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METHODS FOR DETERMINING PERFORMANCE EXPECTATIONS AND OPTIMAL NO BUILD TIMES OF FIELDED JET ENGINES

by

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METHODS FOR DETERMINING PERFORMANCE EXPECTATIONS AND OPTIMAL NO BUILD TIMES OF FIELDED JET ENGINES

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ABSTRACT

This thesis investigates methods for determining fielded jet engine performance goals. Data exported from the Naval Aviation Logistics Data Analysis (NALDA) data base was fitted by a Weibull distribution to obtain the engine probability density function, cumulative density function, mean time between failure, failure rate, and conditional reliabilities. The thesis applies the results of the data analysis by using a commercial software package, Mathcad, to find the solution to an optimizing equation for average maintenance cost per hour of engine critical component operation. The solution yields optimum no build times given the component's Hard Time, ratios of several inspection/repair cost factors, and properties of the failure time probability distributions of the engine and component. The goal is to economize resources by inspecting life limited components when they are available after having accumulated a predetermined number of operating hours. The procedures developed can be used for any aircraft engine or any mechanical component with data that can be fitted to a Weibull distribution and with maintenance cost ratios that fit the model presented herein.

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LIST OF ABBREVIATIONS

θ	Theta - Weibull Distribution Scale Parameter
β	Beta - Weibull Distribution Shape Parameter
A/C	Aircraft
CDF	Cumulative Distribution Function
CFBF	Cannibalization Followed By Failure
CNFBF	Cannibalization Not Followed By Failure
FHSN	Flight Hour Since New
FHSR	Flight Hour Since Repair
HPT	High Pressure Turbine
HT	Hard Time
IMA	Intermediate Maintenance Activity
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
NADEP	Naval Aviation Depot
NALDA	Naval Aviation Logistics Data Analysis
NBT	No Build Time
P/REASON	Previous Reason for Removal
PDF	Probability Density Function
RCM	Reliability Centered Maintenance
RHS	Right Hand Side
REA-REM	Reason for Removal
REM-UIC	Removal Unit Identification Code
R(t)	Reliability at time t (Probability of surviving first t hours)

SERNO	Serial Number
SI	Significant Item
SSC	Status Star Code
STD DEV	Standard Deviation
T	Operating Time to Failure Since Last Repair of a Randomly Selected Engine
t	Hours Accumulated on Randomly Selected Engine Since Last Failure
T_o	Critical Component Hard Inspection Time
t_o	Component Optimal No Build Time

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I. INTRODUCTION

A. BACKGROUND

1. Reliability Centered Maintenance

Until the late 1960s, the traditional maintenance approach for aircraft engines in both the commercial airline industry and military was to perform maintenance on a scheduled overhaul basis. However, research proved that engine reliability was not significantly improved by scheduled overhauls after a predetermined time period. As a result, a new maintenance approach called Reliability Centered Maintenance, or RCM, was developed based on reliability analysis. RCM, by formal definition, is the application of a disciplined logic or methodology to identify preventative maintenance tasks in order to realize the inherent reliability of a piece of equipment with the minimum expenditure of resources. Because it is a disciplined process, there are clearly definable steps to be followed when performing RCM. [Ref 1]

a. Significant Items

The first step in the RCM process for aircraft engines is to determine the functionally significant items. These are items whose failure could directly or indirectly affect safety of flight, result in severe damage or equipment loss, or have a significant economic impact. The list of significant items in an engine is a well-defined group that changes little except for the introduction of major new technologies. Significant Items are subjected to a Failure Modes, Effects, and Criticality Analysis (FMECA), which looks at the manner or mode in which the item might fail, the impact of the item's failure, and the

impact of the failure mode on the operation of the engine. From this analysis, a preventative maintenance program is developed for the engine. [Ref 2]

b. Hard Inspection Times

The RCM analysis also identifies preventative maintenance tasks (basic servicing, inspection, test, calibration, and inspection) and task frequency. One specific process task is called Hard Time (HT) task. HT tasks relate to items with life limits that must be removed for inspection at the end of an expired operating period. [Ref 2]

c. Life Limited Components

Major engine subassemblies, such as the compressor section, have indentured components with individually designated life limits. When these life limited components reach a predetermined number of operating hours they are removed for inspection and are either reconditioned and returned to service or scrapped. These items are also commonly referred to as "critical components" or "high-time components. Critical or high time components are items which must be removed for inspection after reaching a designated accumulated number of operating hours. HT differs from on-condition inspection in that on-condition inspections are performed on items for a specific cause other than operating hours. [Ref 2]

d. No Build Times

When an engine has been removed from an aircraft for repair it follows that a decision should be made, because the engine is available, as to whether or not to inspect high time components which themselves are not the cause of the engine failure. The smallest predetermined operating time accumulated on a non-failed critical component when the decision is made to inspect it at the same time its mother engine is under repair is called

its No Build Time, or NBT. The goal is to economize resources by inspecting life limited components while they are readily available. One of the purposes of this thesis is to present a methodology for computing optimum NBT of a critical component given its HT, ratios of several inspection/repair cost factors, and properties of the failure time probability distributions of the engine and the critical component.

B. REVIEW OF PREVIOUS RESEARCH

This thesis is a continuation of work previously conducted by LT Michael R. Caudill and LT John A. Malsbury in the area of performance goal setting for fielded jet engines. Their research included parametric and non-parametric statistical analysis of engine removal data for the TF-34 engine over a five year period using the NALDA data base. Probability density functions, cumulative density functions, mean time between failures, failure rates, and conditional reliabilies for the engine were obtained for a number of different data filters. In particular, various subsets of the data base were fitted by a Weibull distribution to allow development of closed form expressions for the probability distributions of the time between failure. These functions can be used for more advanced research in the area of setting inspection times and no build times.

C. RESEARCH QUESTIONS

The overall guiding questions for this thesis are:

- What is the effect on engine MTTF and R(t) if residual life data is included in the Weibull analysis of failure population?
- Do the engines chosen for cannibalization have a characteristic that is unlike the engines that are not chosen for cannibalization?

- Can a method be established to determine cost effective no build times relative to hard inspection times for critical components of an aircraft engine?

- If a method can be established to determine optimum no build times, are the no build times currently in use for the TF-34 engine realistic? If not, what should they be?

D. METHODOLOGY FOR NO BUILD TIMES

A mathematical model to calculate no build times was developed by Professor W. M. Woods and is used herein. In using the model, engine Weibull parameters were estimated using values calculated from actual data analysis, and component Weibull parameters values were assigned.

E. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The scope of the research of this thesis was limited to the TF-34 engine, however, the logic and methodology used in determining optimal no build times can be used for any engine, or any mechanical component with data that can be fitted to a Weibull distribution and maintenance cost ratios similar to those used in the model presented herein.

This thesis uses predetermined parameter values for the probability distribution of the engine, assigned parameters values for the probability distribution of the components, a wide range of maintenance cost ratios, and component hard inspection times similar to those being used.

F. THESIS ORGANIZATION

This thesis is divided into five chapters including the Chapter I introduction. Chapter II is further statistical analysis of the engine failure data. Chapter III is an explanation of the optimal equation for NBT. Chapter IV presents a sensitivity analysis of the Mathcad software package and a sensitivity analysis of the optimum NBT equation. Finally, Chapter V presents a summary, conclusions and recommendations.

II. FURTHER STATISTICAL ANALYSIS OF ENGINE FAILURE DATA

A. INCLUSION OF RESIDUAL LIFE DATA

Caudill [Ref 3] filtered the five year data base and obtained 723 operating times between engine failures. Various subsets of these failure times were used in both non-parametric and parametric analysis to compute the engine mean time between failure (MTBF), probability density function, cumulative density function, failure rate, and conditional reliabilities. The purpose of this section is to determine the effect on the engine performance parameters if residual life data is included along with the operating times between failures. The filtered subset of failure times that had the zero failure times removed is used in this analysis. Of the 723 operating times between failures, 39 were zeros resulting in 684 true failure times.

The failure times data base was screened for engines which had operating time accumulated after their last failure. If the last recorded failure removal was followed by a non-failure removal such as an inspection, cannibalization, or directed removal the operating time on the engine after the last failure was calculated using the engine age at the respective time of removal. The following procedure was used to determine these residual operating times:

Step 1: Sort the entire NALDA data base by engine serial number and isolate each different engine serial number.

Step 2: Sort each series of engine serial numbers by flight hour since new (FHSN) in ascending order to get a chronological history of the engines with failure removals.

Step 3: For each serial number that had a non-failure removal after its last failure, subtract the FHSN at the time of last failure from FHSN at time of non-failure removal.

Appendix A presents the data base of the results of this procedure. There were 106 residual life times obtained. Appendix B presents indexed failure times and indexed residual life times used in further analysis.

The same equations and procedures used by Caudill were used in this thesis to fit a Weibull distribution to the failure times plus residual operating times data base. The Weibull distribution statistical functions (less zero failure times subset) are presented in Table 2-1. The engine Weibull parameters β and θ increased from 1.3092 to 1.6093 and 558.609 to 687.617, respectively, with the residual life data included. Figures 2-1, 2-2, 2-3, and 2-4 present graphs of these functions compared with failure time (less zeros) only as computed by Caudill.

Table 2-2 presents conditional probabilities for selected values of T, operating time to failure since last repair of a randomly selected engine, and t, hours accumulated on the randomly selected engine since last failure. Values for T are given across the top row and values for t are given in the far left column. For example, in Table 2-2, for T = 300 and t = 50, the probability that an engine will operate without failure to time 500 hours, given it has accumulated 50 hours, is 78.82%. This conditional probability is denoted by R(300|50). These conditional probabilities are presented graphically in Figure 2-5 where T is represented by the different curves, t is the x-axis value, and the conditional probability is the y-axis value. For the same example, R(300|50) is determined from the top set of curves in Figure 2-5. The y-axis off the topmost curve (300 Hrs) at t = 50 shows a probability slightly below 0.80 corresponding with the value from Table 2-2 of 78.72%.

The failure removal data was modified to include all failure times, less zero failure times, less random 50% of failure times less than 100, and less random 80% of failure times less than 100. PDF functions for the modified data bases are presented in Figure 2-6. The graphs indicate that as low value failure times are removed from the data base, both parameter β and θ increase significantly.

Failure Times t	Weibull PDF f(t)	Weibull CDF F(t)	Failure Rate h(t)	Reliability R(t)
0	0.0000	0.0000	0.0000	1.0000
50	0.0005	0.0146	0.0005	0.9854
100	0.0007	0.0439	0.0007	0.9561
150	0.0008	0.0827	0.0009	0.9173
200	0.0010	0.1281	0.0011	0.8719
250	0.0010	0.1782	0.0013	0.8218
300	0.0011	0.2314	0.0014	0.7686
350	0.0011	0.2863	0.0016	0.7137
400	0.0011	0.3418	0.0017	0.6582
450	0.0011	0.3968	0.0018	0.6032
500	0.0011	0.4506	0.0019	0.5494
550	0.0010	0.5025	0.0020	0.4975
600	0.0010	0.5520	0.0022	0.4480
650	0.0009	0.5989	0.0023	0.4011
700	0.0008	0.6427	0.0024	0.3573
750	0.0008	0.6834	0.0025	0.3166
800	0.0007	0.7208	0.0026	0.2792
850	0.0007	0.7550	0.0027	0.2450
900	0.0006	0.7861	0.0028	0.2139
950	0.0005	0.8141	0.0028	0.1859
1000	0.0005	0.8391	0.0029	0.1609
1050	0.0004	0.8614	0.0030	0.1386
1100	0.0004	0.8812	0.0031	0.1188
1150	0.0003	0.8985	0.0032	0.1015
1200	0.0003	0.9137	0.0033	0.0863
1250	0.0002	0.9269	0.0034	0.0731
1300	0.0002	0.9384	0.0034	0.0616
1350	0.0002	0.9483	0.0035	0.0517
1400	0.0002	0.9567	0.0036	0.0433
1450	0.0001	0.9639	0.0037	0.0361
1500	0.0001	0.9701	0.0038	0.0299
1550	0.0001	0.9752	0.0038	0.0248
1600	0.0001	0.9796	0.0039	0.0204
1650	0.0001	0.9833	0.0040	0.0167
1700	0.0001	0.9863	0.0041	0.0137
1750	0.0000	0.9889	0.0041	0.0111
1800	0.0000	0.9909	0.0042	0.0091
1850	0.0000	0.9927	0.0043	0.0073
1900	0.0000	0.9941	0.0043	0.0059
1950	0.0000	0.9953	0.0044	0.0047
2000	0.0000	0.9962	0.0045	0.0038

RECORDS	**684**
TRIAL	683.9999
BETA	1.6093
THETA	687.617
MTBF	613.650
VARIANCE	166231
STD DEV	407.714

	Value
1+1/BETA	1.621
1+2/BETA	2.243

Gamma
0.89243
1.14801

Table 2-1. Weibull Distribution Statistical Functions Data
(Failure times (less zeros) plus residual operating times)

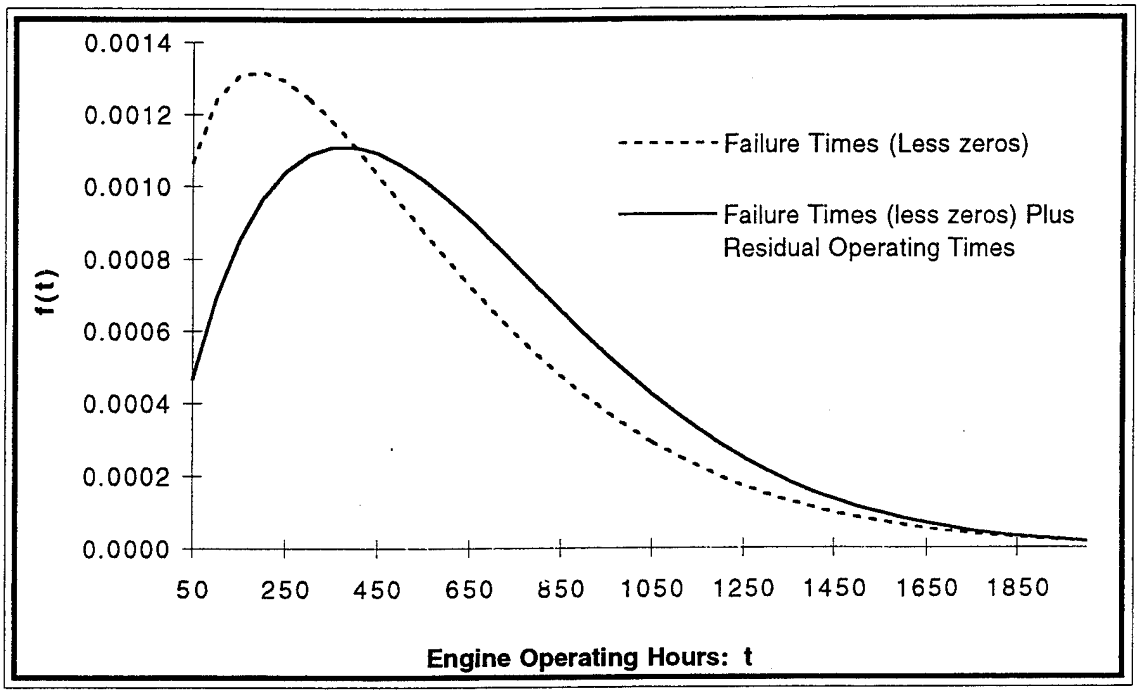

Figure 2-1. Weibull Distribution PDF Comparison

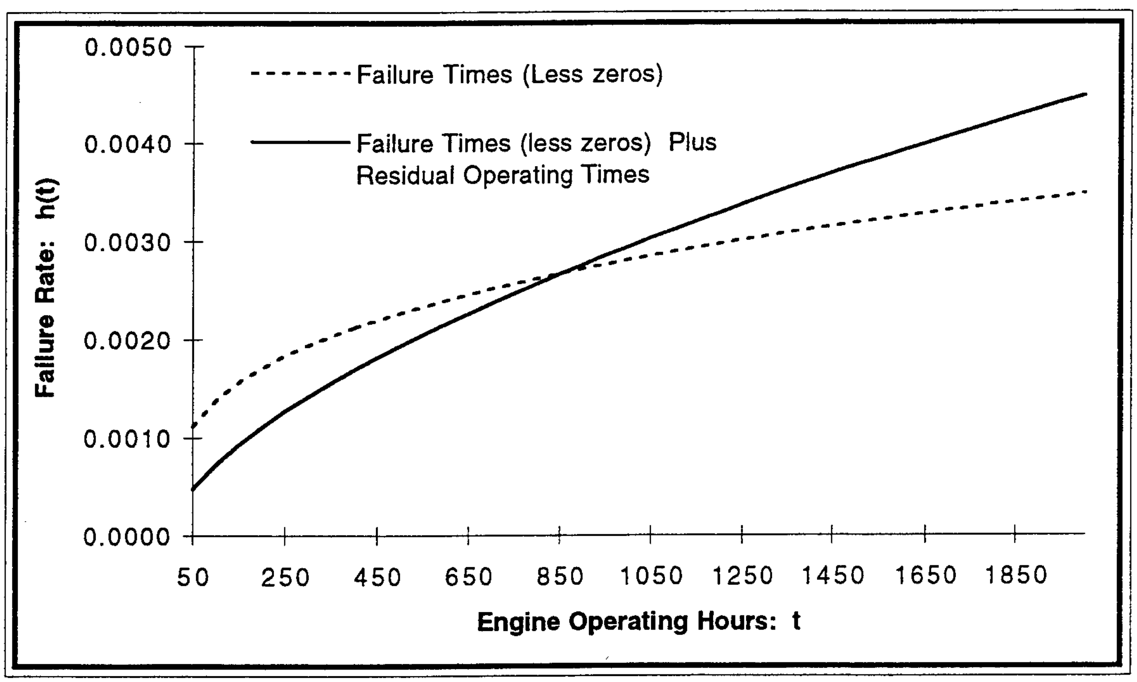

Figure 2-2. Weibull Distribution Failure Rate Comparison

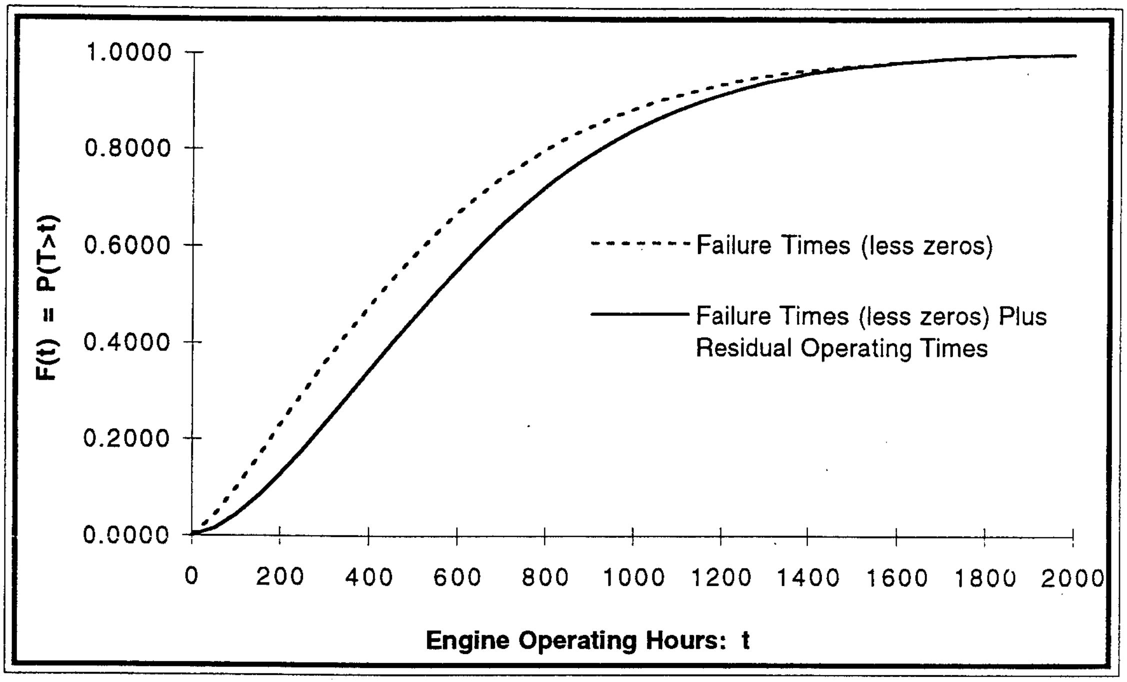

Figure 2-3. Weibull Distribution CDF Comparison

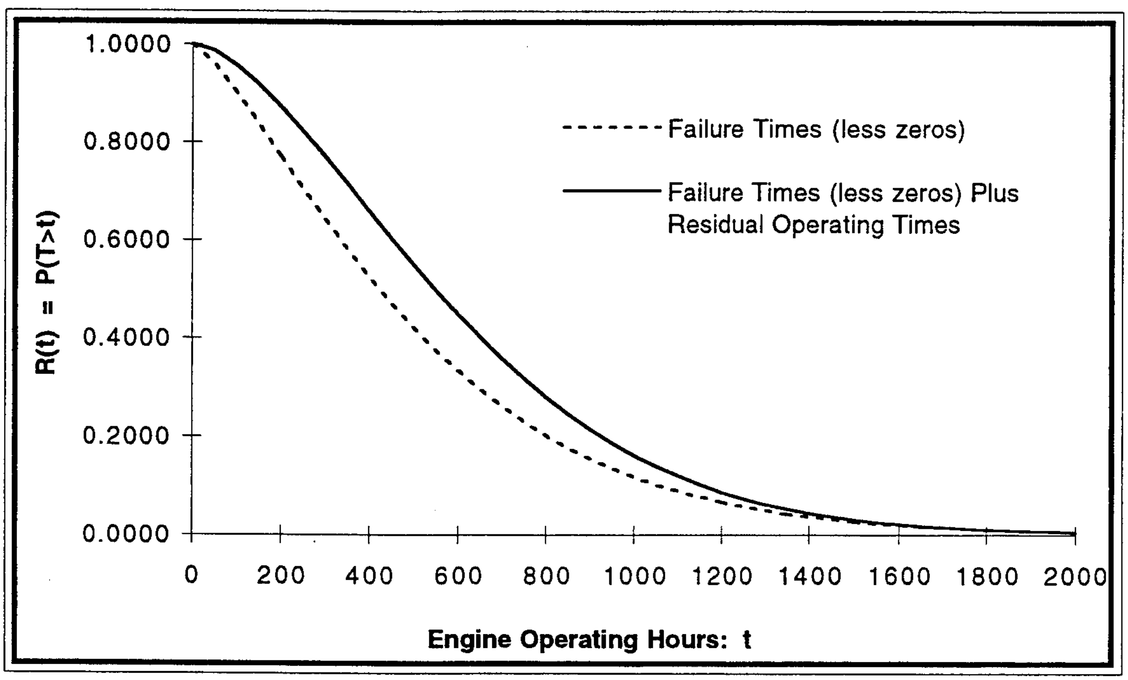

Figure 2-4. Weibull Distribution Reliability Comparison

FHPR	300 Hrs Prob	400 Hrs Prob	500 Hrs Prob	600 Hrs Prob	700 Hrs Prob	800 Hrs Prob	900 Hrs Prob	1000 Hrs Prob	1100 Hrs Prob	1200 Hrs Prob	1300 Hrs Prob	1400 Hrs Prob	1500 Hrs Prob
50	0.7872	0.6721	0.5568	0.4484	0.3516	0.2688	0.2005	0.1461	0.1040	0.0725	0.0494	0.0330	0.0215
100	0.8087	0.6905	0.5720	0.4607	0.3612	0.2761	0.2060	0.1501	0.1069	0.0744	0.0507	0.0339	0.0221
150	0.8405	0.7176	0.5945	0.4788	0.3754	0.2870	0.2141	0.1560	0.1111	0.0774	0.0527	0.0352	0.0230
200	0.8825	0.7535	0.6242	0.5027	0.3942	0.3013	0.2248	0.1638	0.1166	0.0812	0.0554	0.0370	0.0242
250	0.9353	0.7986	0.6616	0.5328	0.4178	0.3194	0.2382	0.1736	0.1236	0.0861	0.0587	0.0392	0.0256
300	1.0000	0.8538	0.7073	0.5696	0.4467	0.3414	0.2547	0.1856	0.1321	0.0920	0.0627	0.0419	0.0274
350		0.9204	0.7625	0.6140	0.4815	0.3681	0.2746	0.2000	0.1424	0.0992	0.0676	0.0451	0.0295
400		1.0000	0.8284	0.6671	0.5231	0.3999	0.2983	0.2173	0.1548	0.1078	0.0735	0.0490	0.0321
450			0.9069	0.7303	0.5727	0.4378	0.3265	0.2379	0.1694	0.1180	0.0804	0.0537	0.0351
500			1.0000	0.8053	0.6315	0.4827	0.3601	0.2624	0.1868	0.1301	0.0887	0.0592	0.0387
550				0.8943	0.7013	0.5361	0.3999	0.2913	0.2075	0.1445	0.0985	0.0657	0.0430
600				1.0000	0.7841	0.5994	0.4471	0.3258	0.2320	0.1616	0.1101	0.0735	0.0481
650					0.8826	0.6747	0.5033	0.3667	0.2611	0.1819	0.1240	0.0827	0.0541
700					1.0000	0.7644	0.5702	0.4154	0.2958	0.2061	0.1405	0.0937	0.0613
750						0.8716	0.6502	0.4737	0.3373	0.2349	0.1601	0.1069	0.0699
800						1.0000	0.7460	0.5435	0.3870	0.2696	0.1837	0.1226	0.0802
850							0.8611	0.6274	0.4468	0.3112	0.2121	0.1416	0.0925
900							1.0000	0.7286	0.5188	0.3614	0.2463	0.1644	0.1075
950								0.8511	0.6061	0.4221	0.2877	0.1920	0.1256
1000								1.0000	0.7121	0.4960	0.3381	0.2256	0.1475
1050									0.8415	0.5861	0.3995	0.2666	0.1743
1100									1.0000	0.6965	0.4747	0.3168	0.2072
1150										0.8323	0.5673	0.3786	0.2475
1200										1.0000	0.6816	0.4549	0.2974
1250											0.8234	0.5495	0.3593
1300											1.0000	0.6674	0.4363
1350												0.8148	0.5327
1400												1.0000	0.6538
1450													0.8065
1500													1.0000

Table 2-2. Weibull Distribution Conditional Probabilities
(Failure Times Plus Residual Life Data)

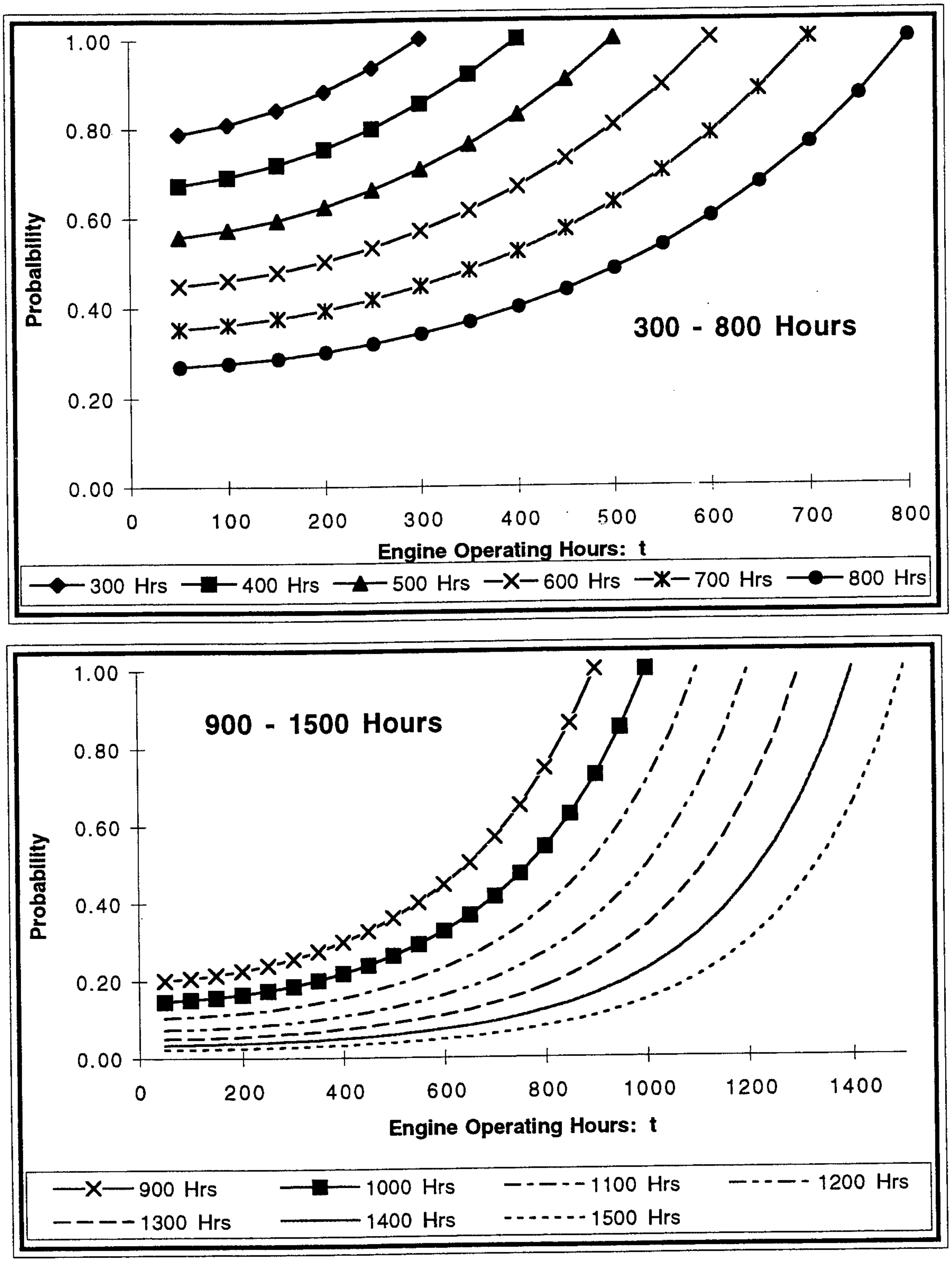

Figure 2-5. Conditional Probabilities With Residual Operating Times

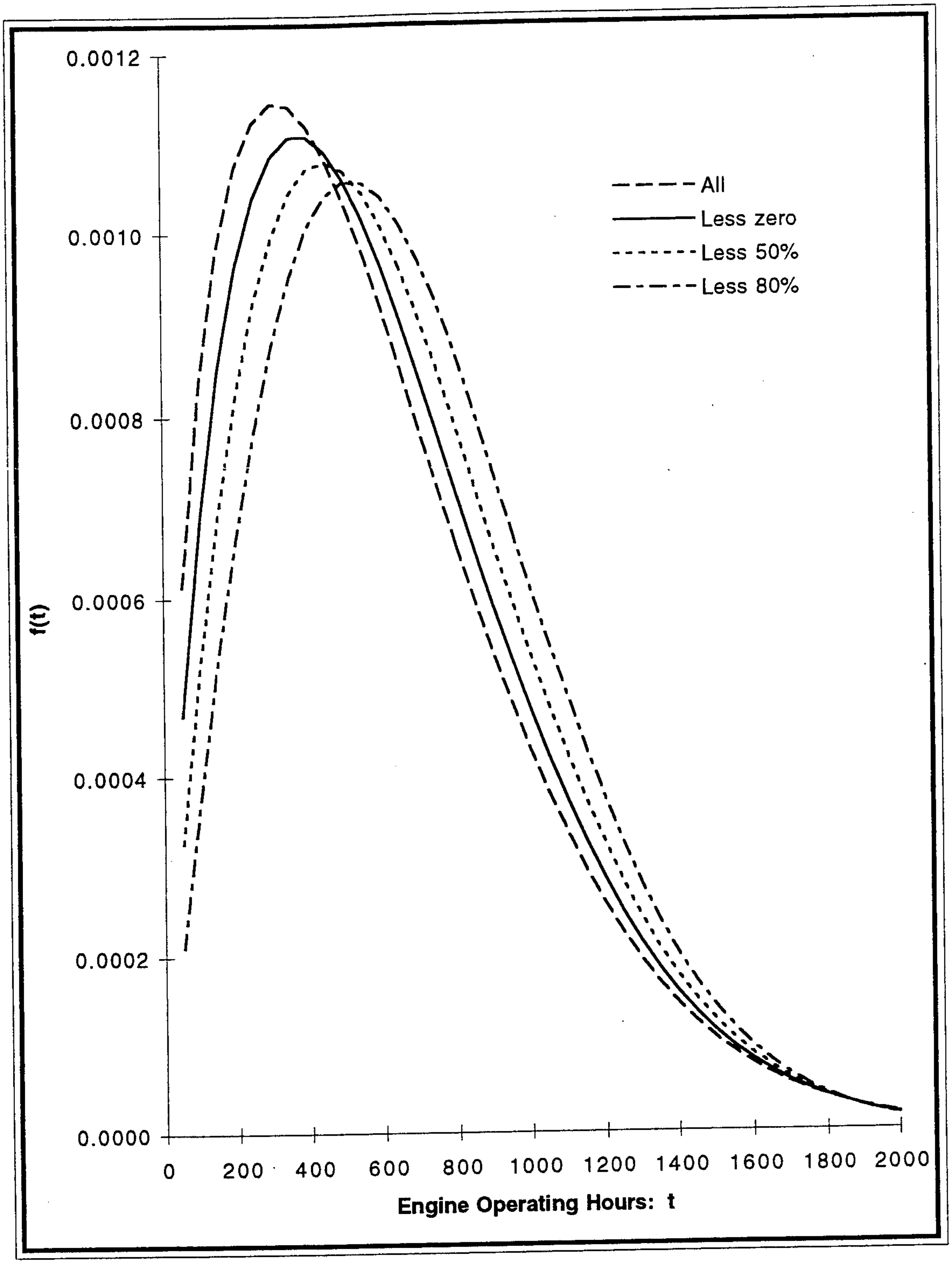

Figure 2-6. Weibull Distribution PDF Comparison

B. AFFECTS OF CANNIBALIZATION ON MTBF

1. Characteristics of Cannibalizations Followed by Failure

Caudill observed a correlation between cannibalization actions and subsequent time to failure. Malsbury [Ref 4] further validated the correlation in an analysis by fiscal year. This section analyzes the data further to determine if there is any difference between two groups of cannibalization actions: (1) cannibalization actions that are directly followed by *failure* removal as presented by Caudill and Malsbury, and (2) cannibalization actions that are directly followed by *non-failure* removal.

A comparison of FHSR and FHSN, at the time of cannibalization, was performed for these two groups. There were a total of 554 cannibalization actions during FY90 - FY94. 171 of these cannibalization actions fall within the first group, i.e., the very next removal was for a failure reason. The remaining 383 cannibalization actions fall within the second group, i.e., the very next removal was for a non-failure reason. Table 2-3 presents the results of the comparison of these two groups. The comparison shows that there is no significant difference in terms of FHSN and FHSR for these two groups. This indicates that FHSN and FHSR are not taken into consideration when engines are cannibalized.

2. Failures Across Cannibalization

A comparison of failure times which crossed cannibalization (i.e., engines which were cannibalized between failure removals) and failure times which did not cross cannibalization (i.e., no cannibalization between the failure removals) was conducted to see the affect on MTBF. Table 2-4 shows that failure times which crossed cannibalization had a MTBF of 632 while failure times which did not cross cannibalization had a MTBF of 426. Caudill [Ref 3: p. 39] found that engines which crossed cannibalization had a MTTF after cannibalization of 247.

Category	FY	No	Avg FHSN	Avg FHSR
Canns Directly Followed by Failure	90	31	4252	436
	91	37	4224	314
	92	42	4733	425
	93	44	4541	384
	94	17	5021	450
		171	4554	402
Canns Not Directly Followed by Failure	90	128	4146	498
	91	97	4536	556
	92	82	4817	453
	93	25	4978	519
	94	51	5469	407
		383	4789	487
Total Cannibalization Actions		554		

Table 2-3. Comparison of CFBF and CNFBF

Category	FY	No	MTBF
True Failures	90	172	411
	91	148	507
	92	157	501
	93	121	489
	94	99	499
		697	481
Failures Across Cannibalization	90	31	512
	91	37	561
	92	42	734
	93	44	686
	94	17	665
		171	632
Failures Without Cannibalization	90	141	389
	91	111	497
	92	115	414
	93	77	375
	94	82	455
		526	426

Table 2-4. Comparison of MTBF Across Cannibalization

III. ESTABLISHING OPTIMAL NO BUILD TIMES

A. OPTIMAL NO-BUILD TIME EQUATION

This chapter explains the equation for computing optimal no-build times relative to hard inspection times of critical components.

The equation uses the Weibull distribution to model the time to failure of an aircraft engine and also for the time to failure of a critical component. The Weibull probability density function is:

$$f(t) = \left(\frac{\beta}{\theta^{\beta}}\right) t^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \tag{1}$$

The shape parameter, β, is a measure of the rate of wear out. The scale parameter, θ, is a measure of the mean time to failure. The failure rate function h(t), for the Weibull distribution is:

$$h(t) = \frac{\beta}{\theta^{\beta}} t^{\beta-1} \tag{2}$$

The true mean time to failure, MTTF, of the Weibull distribution is:

$$\text{MTTF} = \theta\Gamma\left(1 + \frac{1}{\beta}\right) \tag{3}$$

where $\Gamma(x)$ is the gamma function. If $\beta=1$, this density function is the exponential density. Analyses of the TF-34 engine NALDA data performed by Caudill and Malsbury indicates $1.2 < \beta < 1.5$. The value of β is almost certainly smaller for the critical components. The reliability function $R(t)=P(T>t)$ for this distribution is:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \tag{4}$$

The conditional reliability function

$$R(t \mid x) = P(T > t \mid T > x), \quad \text{t>x is}$$

$$R(t \mid x) = \frac{e^{-\left(\frac{t}{\theta}\right)^{\beta}}}{e^{-\left(\frac{x}{\theta}\right)^{\beta}}} = e^{-\left[\left(\frac{t}{\theta}\right)^{\beta} - \left(\frac{x}{\theta}\right)^{\beta}\right]} \tag{5}$$

When applying the Weibull distribution to component failure time in the optimum no-build time equation, the following notation is used:

$\theta = a$ and $\beta = c$ for the critical component

and

$\theta = b$ and $\beta = d$ for the engine.

The remaining parameters in the optimization equation are the following:

y = T_o: Hard inspection time of the critical component

u = C_n: Cost to perform a component hard inspection when the engine is already off the wing and being repaired due to some failure other than the critical component.

v = C_i: Cost to perform the hard inspection of the critical component when the engine is still operational; i.e., still on the wing. This cost will include the cost to remove the engine from the wing and break the engine down. This removal cost is not included in u.

w = C_f: Cost to inspect/repair/replace the critical component after it has failed.

x = t_o: Optimum no-build time for the component; i.e., if the operating time accumulated on the critical component when the engine has been removed from the wing for repair or whatever is greater than t_o, then the engine should not be rebuilt without inspecting/repairing/replacing the critical component.

The optimal no build time equation is:

$$\frac{u}{x} := u\int_0^{y-x} \frac{1}{t+x}\left(\frac{1}{b}\right)^{d}(d)(t)^{d-1} e^{-\left[\left(\frac{t}{b}\right)+\left(\frac{t+x}{a}\right)-\left(\frac{x}{a}\right)\right]} dt + \frac{v}{y} e^{-\left[\left(\frac{y-x}{b}\right)-\left(\frac{y}{a}\right)+\left(\frac{x}{a}\right)\right]} + w\int_x^{y} \frac{1}{t}\left(\frac{1}{a}\right)(c)(t)^{c-1} e^{-\left[\left(\frac{t}{a}\right)+\left(\frac{x}{a}\right)-\left(\frac{t-x}{b}\right)\right]} dt \tag{6}$$

In the optimizing equation, the left member, u/x, denotes the cost per unit hour to perform hard inspection/repair on the critical component if inspection is done now when the engine is already off the wing for some reason and has accumulated x operating hours. The right hand side (RHS) of the equation is the average cost per unit time to perform hard inspection/repair of the critical component, if we do not do the inspection now, when the engine is off the wing, but do it at any one of the three following opportunities:

a) When the engine fails at a future time, before the operating time on the critical component reaches its hard inspection time, y, is taken off the wing for repair, and the critical component has not failed (first term of the RHS).

b) When the operating time on the critical component has accumulated to the designated hard inspection time, y, and the engine has not failed since it has been reinstalled on the wing (second term of the RHS).

c) When the critical component has failed prior to its hard inspection time and the engine has not failed since last installation up to the time the critical component failed (third term of the RHS).

If it is decided to wait for another chance to do hard inspection when the engine has been removed again (for repair), the operating cost per unit time to do the hard inspection when the engine fails at t hours after reinstallation (operating time on component is x+t) is u/(t+x). To get the average cost per unit time this cost must be multiplied by the "probability" (density function) of engine failure at time t times the probability the component "lives" beyond x+t hours given it is "alive" at time x and integrated across all times between x and y; i.e., for $0 < t < (y - x)$. The time t in this integral is time on the engine after reinstallation and t+x is total time accumulated on the component.

The second term is the cost per operating hours, v/y, to do hard inspection when the engine is on the wing at the time y hours is accumulated on the component times the probability that the engine has not failed in the (y-x) hours after reinstallation times the probability the component lives beyond y hours given it was alive at x hours.

The third term is the cost per unit time, w/t, of doing hard inspection on the critical component when the component fails at its operating time t given it was alive at time x times the probability the engine lives (except for the component) beyond time t-x. This is an average cost per unit time. In this term, the variable t is time accumulated on the component (from birth or since last repair).

If a component has accumulated more than the optimal number of hours, x, when its parent engine is removed for repair, then it would be cost effective to inspect/repair/replace the component as well before reinstalling the engine. Therefore, x is the optimal no build time.

Figure 3-1 is a Mathcad printout presenting the solution for optimal NBT for one set of values for Cn, Ci, and Cf, and their ratios as well, while all other parameters are held constant. The symbol := is "defined as." The number x:= 200 at the top of the printout is an initializing value the software package needs to solve the equation. The values of u, v, w, (i.e. Cn, Ci, Cf) are 500, 750, 1000 respectfully which yield cost ratios of Ci/Cn = 1.5 and Cf/Cn = 2. The component has a MTTF (Weibull shape parameter), a, of approximately 4000 hours and a wear-out parameter, c, of 1.2. The engine has a MTTF (Weibull shape parameter), b, of approximately 500 hours and a wear-out parameter, d, of 1.3. The hard inspection time, y, is 1000 hours. The optimal value of x, i.e., the solution for x, is the value on the RHS of the g(a, b, c, d, u, v, w, y) term. In this case the optimal no-build time is 798 hours.

Note in the solution that one only need know the ratios Ci/Cn, Cf/Cn, and Cn and not the values of Ci and Cf to fine the optimal NBT x. That is, x depends on Cn, Ci/Cn, and Cf/Cn. This can be seen by dividing the equation through by u (i.e. Cn) in the optimizing equation.

Table 3-1 displays a summary of a Mathcad solution printout with the no build time solutions of 763 and 586 hours respectively for the same set of parameters values and cost ratio pairs of (2,4) and (4,10).

x:=200

given

$$\frac{u}{x} := u\int_0^{y-x} \frac{1}{t+x}\left(\frac{1}{b}\right)^d (d)(t)^{t-1} e^{-\left[\left(\frac{t}{b}\right)+\left(\frac{t+x}{a}\right)-\left(\frac{x}{a}\right)\right]} dt + \frac{v}{y} e^{-\left[\left(\frac{y-x}{b}\right)-\left(\frac{y}{a}\right)+\left(\frac{x}{a}\right)\right]} + w\int_x^y \frac{1}{t}\left(\frac{1}{a}\right)(c)(t)^{c-1} e^{-\left[\left(\frac{t}{a}\right)+\left(\frac{x}{a}\right)-\left(\frac{t-x}{b}\right)\right]} dt$$

g(a, b, c, d, u, v, w, y) := find (x)

u:= 500
v:= 750
w:= 1000
a:= 2000
c:= 1.2
b:= 500
d:= 1.3
y:= 1000

g(a, b, c, d, u, v, w, y) = 798

Figure 3-1. Mathcad Solution for Optimum NBT

Cost ratio pair (u = 10,000) =	(2, 4)	(4, 10)
x:=	200	200
u:=	10000	10000
v:=	20000	40000
w:=	40000	100000
a:=	4000	4000
c:=	1.2	1.2
b:=	500	500
d:=	1.3	1.3
y:=	1000	1000
g(a, b, c, d, u, v, w, y) =	**763**	**586**

Table 3-1. Mathcad printout summary

IV. SENSITIVITY ANALYSIS OF SOLUTION METHOD AS A FUNCTION OF COST RATIOS

A. MATHCAD PROCEDURES AND SENSITIVITY

1. Mathcad Solver Procedures

Mathcad is a windows based software package that combines the mathematical solution capabilities of an electronic spreadsheet with the equation editor capabilities of a word processor. This combination allows an equation to be typed into the program and solved as it actually appears. [Ref 5]

Mathcad has the capability to solve systems of equations and can be used to find optimizing solutions. In the case of the optimizing equation for NBT, as presented in equation (6) in Chapter III, code is entered into the Mathcad worksheet as depicted in Figure 3-1. Mathcad's solution value for x from the NBT equation appears on the RHS of the term g(a, b, c, d, u, v, w, y). The constants are engine/component parameters, maintenance cost ratios, and component hard times as previously defined in Chapter III. Changes in any of these constants will likely yield different solution values for x. Changing only u, v and w by a common multiple will not yield a different solution because their ratios remain unchanged.

2. Mathcad Solver Sensitivity

Before determining the effects of changes in any of the different parameters on the solution of the optimizing equation for NBT it was first necessary to determine the sensitivity of the Mathcad package itself. Using the Mathcad solver it was observed that different values of the cost ratio Cf/Cn had no effect on the solution given set values of

other parameters. Moreover, changing the values of cost inputs while holding cost ratios and other parameters constant resulted in different solutions values for x.

To determine the sensitivity of the Mathcad solver, solution values for x were obtained for three different cost ratio pairs with the other parameters being held constant. The Mathcad solution value for x was entered into the RHS of the optimizing equation which was defined simply as f(x). The input cost, u, was then divided by the solution for x and the result was compared to f(x). They should be equal. Table 4-1 compares the values of u/x and f(x) for the three cost ratio pairs. Because the values of u/x and f(x) are not equal, it was concluded that the solution for x given by the Mathcad command used in Figure 3-1 is not always the optimal value for x. This problem is due to round off error in the Mathcad solution method.

u= 10,000	Ci/Cn	Cf/Cn	x	u/x	f(x)
a = 2000	2	3	787	12.71	18.69
b = 500	3	4	683	14.64	24.90
c = 1.0	4	5	615	16.26	30.41
d = 1.2					
y = 1000					

Table 4-1. Mathcad Solver Solutions for "x" and Comparison of u/x and f(x)

3. Mathcad Graphical Solution Procedures

A graphical solution method using Mathcad was performed to resolve the round off error problem. The same input cost value, u, and the three cost ratio pairs were used to test this procedure. The following methodology was used to enter code into the Mathcad worksheet:

Step 1: Define values for the constants.

Step 2: Define a range for the variable x.

Step 2: Define the optimum NBT equation as f(x).

Step 3: Define u/x as g(x).

Step 4: Using the Mathcad graphing capabilities read the optimum solution for x as the intersection of the curves for f(x) and g(x).

Figure 4-1 is an example of a typical Mathcad graphical solution printout. In Figure 4-1 the optimum value, x_o, of x is 638 hours.

4. Mathcad Graphical Solution Sensitivity

As with the solver solution method, the graphical solution for x was entered into the RHS of the optimizing equation expressed as f(x) and compared to u/x. Table 4-2 presents this comparison for the same three scenarios. It shows that that u/x equals f(x) for the three cost ratio pairs.

u= 10,000	Ci/Cn	Cf/Cn	x	u/x	f(x)
a = 2000	2	3	484	20.66	20.68
b = 500	3	4	340	29.41	29.45
c = 1.0	4	5	257	38.91	38.92
d = 1.2					
y = 1000					

Table 4-2. Graphical Solutions for x and comparison of u/x and f(x)

Figure 4-2 presents a Mathcad graphical solution printout for value of x ranging from 100 to 1000. It is a macro-view showing the behavior of the two curves f(x) and

g(x). The curve for f(x) is the RHS of the optimal no build time equation. A point along the f(x) curve is the expected cost per flight hour if it is decided not to inspect the component while the mother engine is being repaired and wait for a chance to do so later. The curve g(x) represents u/x. A point on this curve is the actual cost per flight hour if the component is inspected when the mother engine is under repair and the component has accumulated x flight hours of operation.

Appendix C presents selected macro-view graphical solution printouts showing the behavior of the two curves. These curves can be used to determine reasonable ranges for the no build time around the optimal solution. Anywhere the two curves are relatively close to each other would yield a no build time approaching the optimal solution. For example, in the printout example on page 81 a reasonable range would be from x = 480 to x = 1000. This reasonable range for no build times can be used in conjunction with logistic support factors such as manpower and material availability, scheduling constraints, safety concerns and operational requirements to make intelligent maintenance decisions.

$u := 10000 \quad v := 15000 \quad w := 20000 \qquad a := 2000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \qquad x := 600..700$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

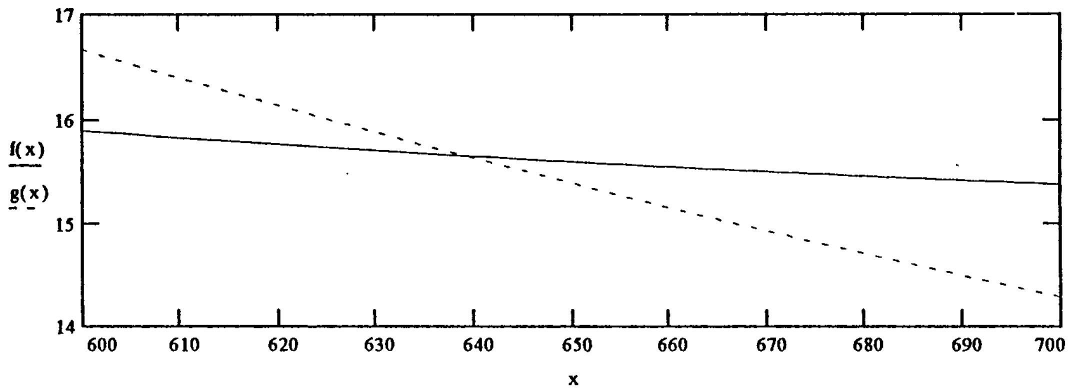

Figure 4-1. Mathcad Graphical Solution Printout

$u := 10000 \quad v := 15000 \quad w := 80000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

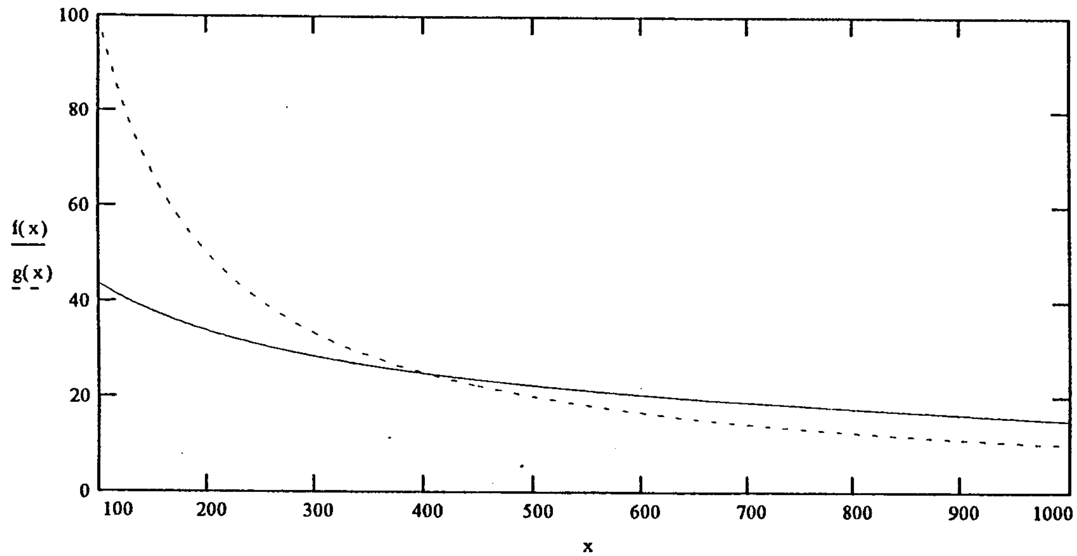

Figure 4-2. Mathcad Graphical Solution Printout for Range x = 100...1000

B. OPTIMAL NO BUILD TIME EQUATION SENSITIVITY

The sensitivity of the optimal NBT equation to changes in the various parameters was determined using the graphical solution method. The equation takes into account three costs: Cn, Ci, and Cf. If the ratios of Ci/Cn and Cf/Cn are known then Ci and Cf can be determined from a given value of Cn and all three costs can then be entered into the equation. Different values of engine and component parameters as well as hard times can then be entered into different cost ratio scenarios.

An input value for u of 10,000 was used along with cost ratio assumptions of $v/u < w/u$ where $3 < w/u < 10$. Ranges for parameter values for the engine and component along with the component hard times used in the sensitivity analysis are presented in Table 4-3.

Parameter:	Low	Middle	High
Theta Component (a)	2000	4000	6000
Beta Component (c)	1.0	1.2	1.5
Theta Engine (b)	500	700	1000
Beta Engine (d)	1.2	1.5	2.0
Component Hard Time (y)	1000		2000

Table 4-3. Sensitivity Analysis Parameter Range Values

The following systematic approach was used to determine the sensitivity of the optimum NBT equation to changes in the engine/component parameters and different component HT:

Step 1: Use lowest range value of each parameter for each cost ratio.

Step 2: Use middle range value of beta and theta component (a and c) with lowest range value of other parameters for each cost ratio.

Step 3: Use highest range value of beta and theta component (a and c) with lowest range value of other parameters for each cost ratio.

Step 4: Use middle range value of theta component (a) with lowest range value of all other parameters for each cost ratio.

Step 5: Use highest range value of theta component (a) with lowest range value of all other parameters for each cost ratio.

Step 6: Use middle range value of beta component (c) with lowest range value of all other parameters for each cost ratio.

Step 7: Use highest range value of beta component (c) with lowest range values of all other parameters for each cost ratio.

Step 8: Use middle range value of beta and theta engine (b and d) with lowest range value of other parameters for each cost ratio.

Step 9: Use highest range value of beta and theta engine (b and d) with lowest range value of other parameters for each cost ratio.

Step 10: Use middle range value of theta engine (c) with lowest range value of all other parameters for each cost ratio.

Step 11: Use highest range value of theta engine (c) with lowest range value of all other parameters for each cost ratio.

Step 12: Use middle range value of beta engine (d) with lowest range value of all other parameters for each cost ratio.

Step 13: Use high range value of beta engine (d) with lowest range value of all other parameters for each cost ratio.

Step 14: Repeat steps 1 through 13 for the component hard time (y) of 2000.

Following these steps yielded 26 different parameter/HT combinations. A tabulation of graphical solution values of x for each of the combinations is presented in Appendix D.

Figures 4-3, 4-4, and 4-5 present some graphical displays of the solutions for x for different cost ratio pairs and parameter values. Figure 4-3 displays curves for different values of Cf/Cn ratios while Ci/Cn is held constant at 1.1 and 1.5. Figures 4-4 and 4-5 shows how the solution for x changes relative to changes in each of the four individual

engine/component parameters for low cost ratio pairs of (1.1, 1.2) and (1.5, 2) and higher cost ratio pairs of (1.5, 6) and (2, 8). As shown in the displays the solution for optimum no build time is particularly sensitive to the value of the cost ratios.

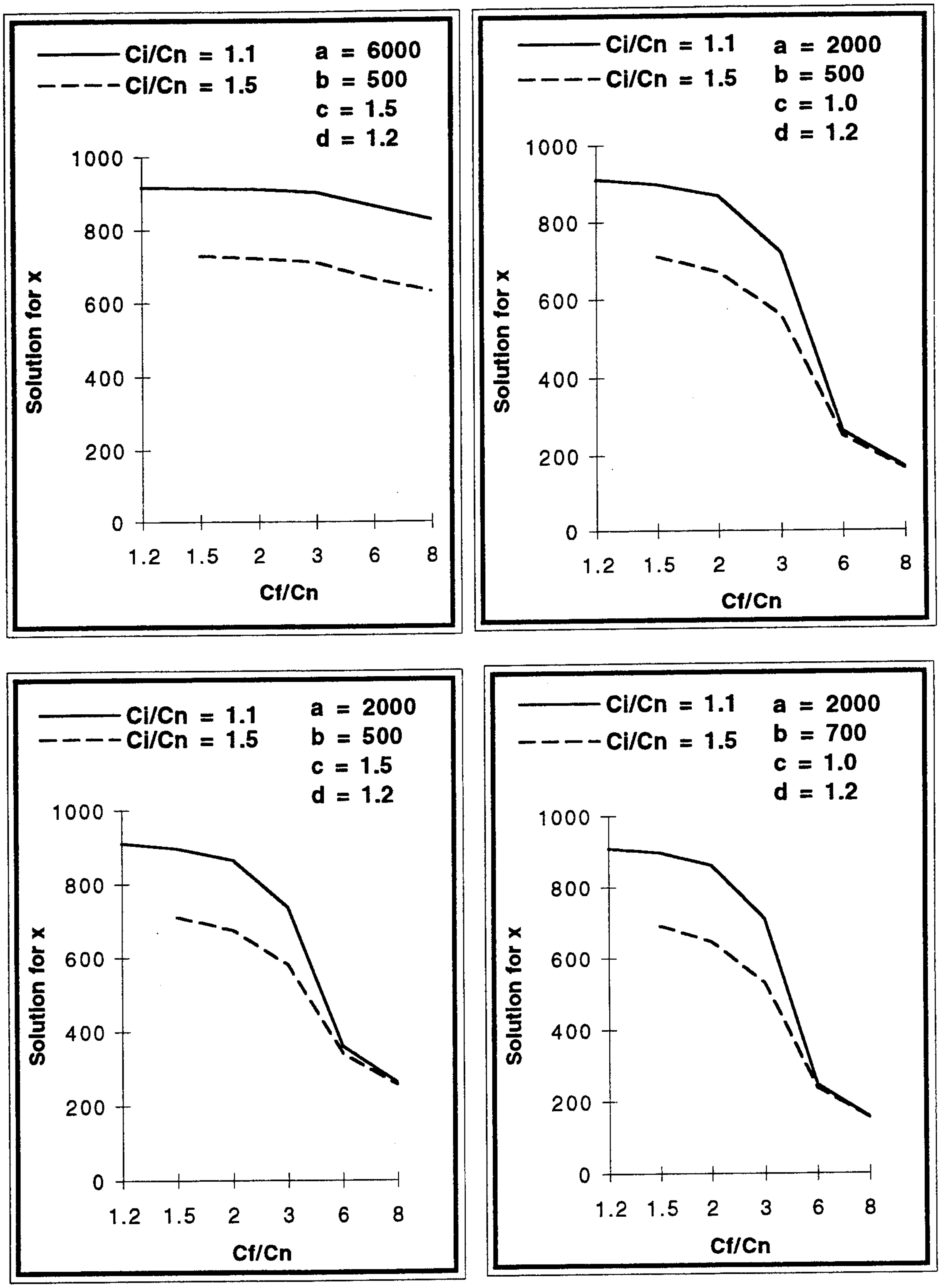

Figure 4-3. Solutions for Constant Parameter Values and Varying Cost Ratio Pairs

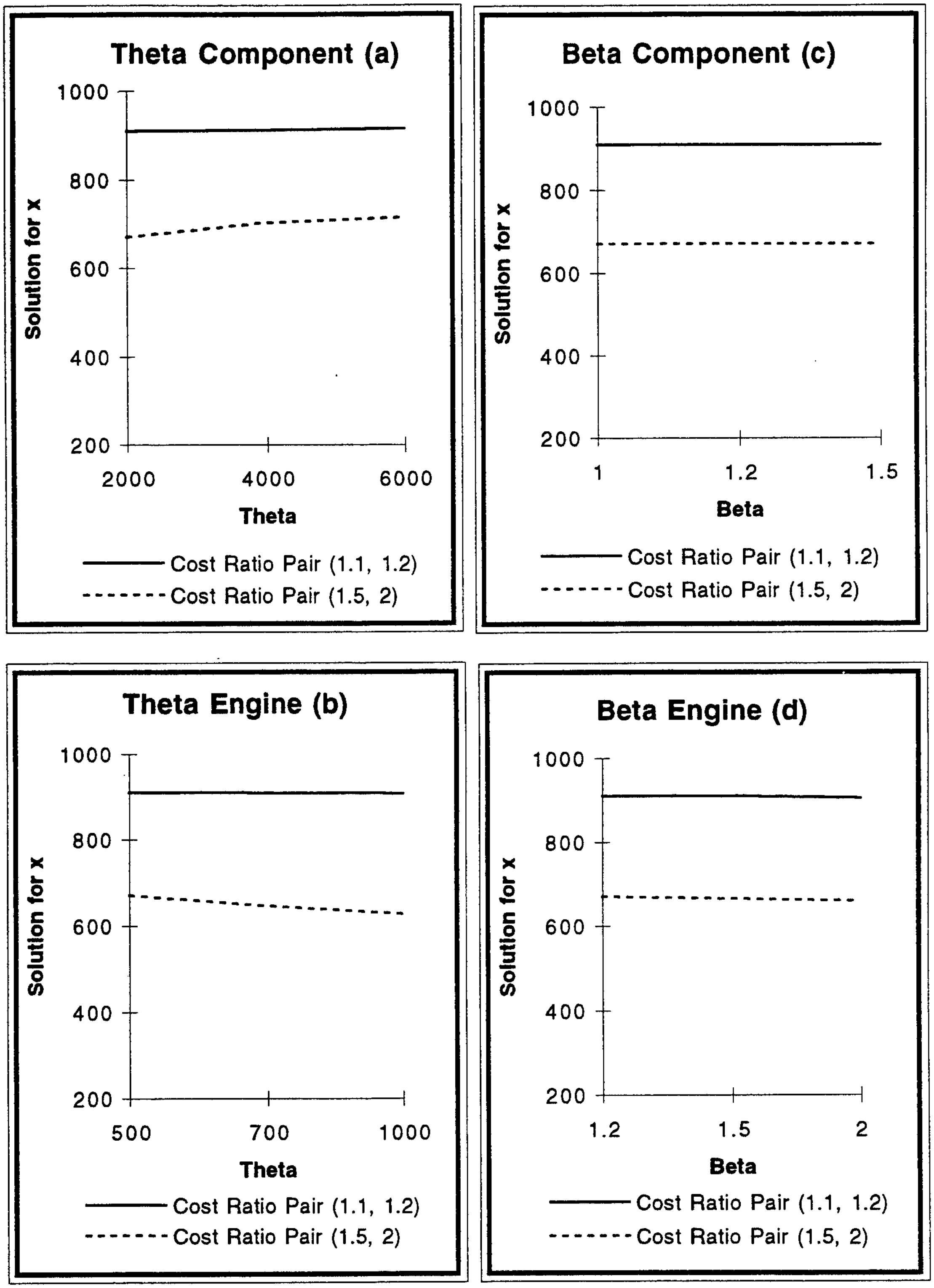

Figure 4-4. Solutions Values for "x" Relative to Changes in Weibull Parameters

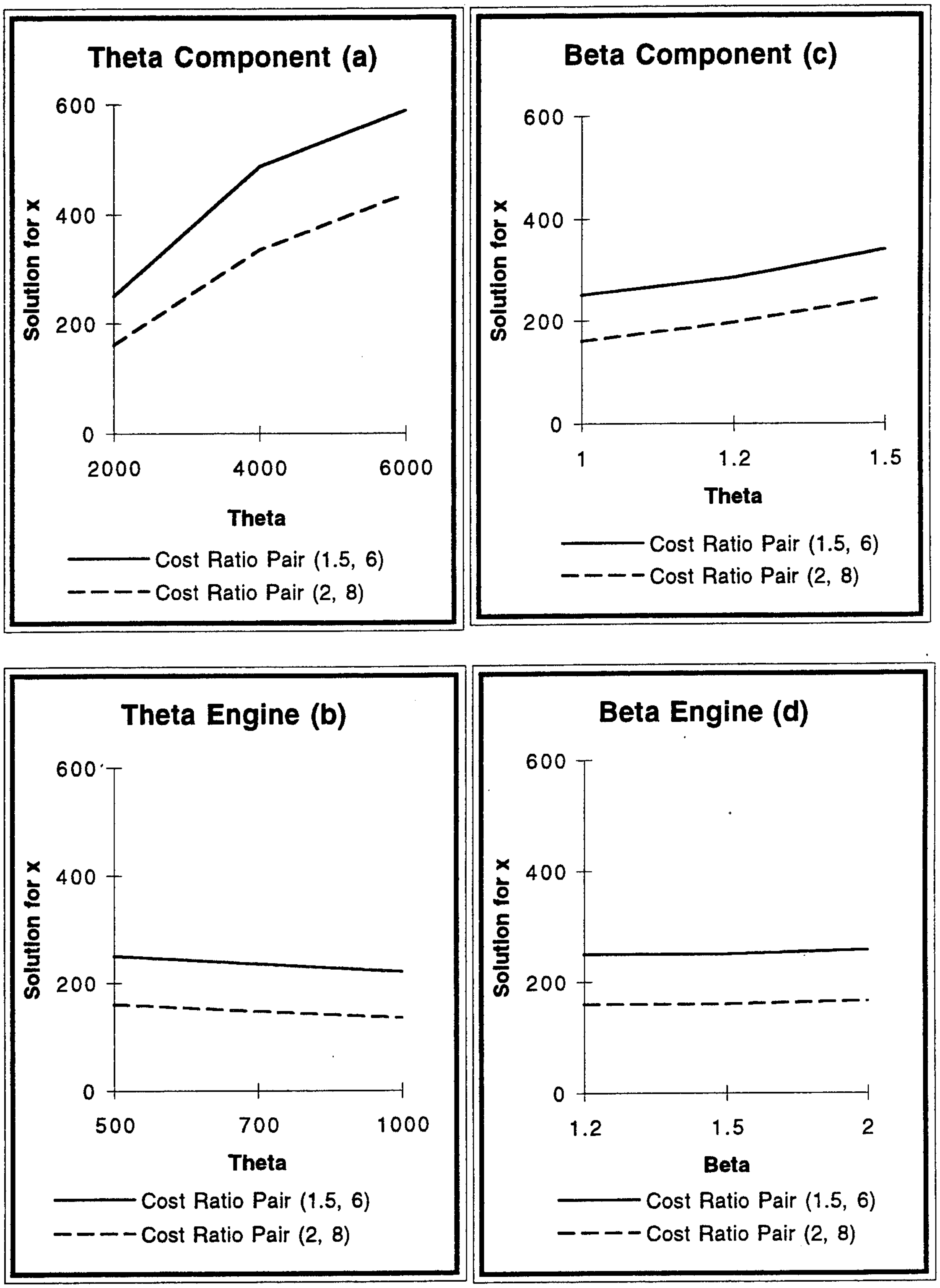

Figure 4-5. Solutions for x Relative to Changes in Weibull Parameters

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

This thesis addressed the following topics:

- The inclusion of residual life data with the engine failure removal times to determine the affect on engine Weibull parameters and related statistical distribution functions for the TF-34.

- Some further analysis of the affect of cannibalization on MTBF.

- Discussion of engine component no built time relative to hard inspection time and maintenance costs.

- Explanation of optimal no build time equation and discussion of method to determine cost effective no build times relative to hard inspection times for critical components of an aircraft engine.

- Demonstration of commercially available software package (Mathcad) to solve for optimal no build times given maintenance cost ratios and engine and component Weibull parameters

- Sensitivity analysis of optimal no build time equation relative to maintenance cost ratios and Weibull parameters.

B. CONCLUSIONS

- Inclusion of the residual life data in with the failure removal data had a significant impact on the statistical measures of the TF-34 engine. This means the reliability of the TF-34 is greater than previously determined using failure data only and residual data should be included in this type of analysis. For the data base subset analyzed in this thesis the Weibull parameter β increased from 1.3092 to 1.6093, and the Weibull parameter θ increased from 559 to 688. These upgraded parameter figures resulted in positive changes to the engine probability density function, failure rate, reliability, and conditional probabilities and engine MTBF.

- It can be concluded that even though cannibalization is random, the high chances of failure following cannibalization actions are relevant and significant. From the further analysis of the affect of cannibalization on MTBF it can be shown that engines chosen for cannibalization are chosen randomly. There is no characteristic distinguishing engines that are not operation at the next removal following cannibalization from engines that are operational at the next removal following cannibalization. However, 30 percent of the cannibalization actions in the data base were engines that subsequently were not operation at the time of next removal.

- Although the mean time to first failure following cannibalization actions is significantly lower than the failure population MTBF, the population of failure times which crossed over cannibalization actions had a higher MTBF than engines with failure times which did not cross over cannibalization actions. This indicated that at the time of cannibalization, some type of corrective maintenance is performed on the engine even though the engine fails in a relatively short period of time following cannibalization

- A valid method was established to determine cost effective no build times relative to hard inspection times for critical components. Using the optimal no build time and the commercial software package Mathcad, optimal times to inspect components can be determined for any combination of maintenance cost ratios pairs, engine and component Weibull parameters, and component hard time.

- The graphical solution procedure is the superior method when determining optimal no build times using Mathcad. The solution yielded by the Mathcad solver is insufficiently accurate for solving our optimization equation when used at the default parameter settings of Mathcad. Graphical solutions also give more insight into the cost implications associated with changing no build time.

- It is important to have accurate cost ratios when using the model. Maintenance cost ratios, as addressed in this thesis, have a significant impact on the solution for optimal no build time. Practical values for these ratios, given $Ci/Cn < Cf/Cn$, are $1.1 < Ci/Cn < 3$ and $1.2 < Cf/Cn < 5$.

- Engine and component Weibull parameters do not have as great an impact on the solution for optimal no build times as do maintenance cost ratios. The parameters that the solution is most sensitive to are θ and β for the component.

- The model presented in this thesis can be used to determine more accurate no build times than the ones currently in use for the TF-34 engine using appropriate maintenance cost ratios - whatever they will be as a fallout of the way inspection is done and what the specific component is.

C. RECOMMENDATIONS

- Continue to use all available data to refine reliability measures for the TF-34 engine in order to get the most realistic statistical function as possible. Reliability measures determined in this thesis were from a five year data base from FY 90 to FY 94. The NALDA data base should be queried for records beyond this period to get more engine failure times and residual operating times for use in the analysis.

- Conduct a review of cannibalization policies for the TF-34 engine to see if there is a way to reduce the number of cannibalization actions. The shear number of cannibalization actions during the five year period covered in this thesis and the fact that 30 percent of the engines which are cannibalized are non-operational at the time of their next removal warrants a study. By reducing the number of cannibalization actions it follows that the number of subsequent failure removals could be reduced thereby resulting in higher readiness rates and lower man-hour expenditures.

- Analyze fleet TF-34 maintenance procedures to see how many of the low failure times may be the result of improper maintenance procedures rather than the inherent reliability of the engine/components. If it is determined that training can be improved then some funding directed towards component improvement can perhaps be directed towards training program improvement.

- Make the model for determining optimal no build times available to the fleet in a user friendly form. Fleet users can then query the NALDA data base for historical removal data on engines and components and subject the data to the same analysis as was performed in this thesis. The analysis can be expanded to all engines in the Navy inventory.

- Optimize resource expenditures in engine maintenance by determining what the actual maintenance costs and maintenance cost ratios are for the TF-34 engine and compare them to the ones calculated in this thesis. This is an area for further study.

- Make historical engine data available to students at NPS by establishing a satellite NALDA data base terminal such as the ones available at major air stations. The data base can be queried for data for use in the thesis process. Much good can be achieved using actual field data and statistical methods taught at NPS.

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APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

A. CONTENTS OF APPENDIX A

Appendix A is the data base sort used to calculate residual operating times. The data base lists the chronological failure removal history of each engine serial number along with the last non-failure removal if applicable. The last non-failure removal is printed in bold type and indicates an engine that has residual operating time following last failure. At that time the engine was removed for a reason other than failure. The serial numbers with no bolded entry have no record of a non-failure removal following last failure. There are 106 engines with residual operating times.

The residual operating time was calculated by taking the flight hours since new at the time of last removal (non-failure) minus the flight hours since new at the time of the previous failure removal. For example, the first entry, serial number 0201021, shows an engine that was removed for failure (reason for removal code 7K) at 3359 operating hours since new. It was subsequently removed for inspection (reason for removal code 7C) at 3893 flight hours since new. The residual operating time is then 3893 - 3359 = 534 hours as indicated.

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

	Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
*	0201021	3359	33	7K	3Q	8910
*	**0201021**	**3893**	**534**	**7C**	**1Z**	**9201**
*	0201022	3076	301	3Q	2N	8910
*	0201022	3115	39	8P	3Q	9008
*	**0201022**	**3549**	**434**	**3W**	**3Q**	**9110**
*	0201101	4805	685	4P	5G	9002
*	0201101	5295	490	1Z	6F	9109
*	0201102	5148	310	4M	5G	9003
*	0201102	5236	88	1Z	4M	9106
*	0201102	6068	832	3T	7C	9406
*	0201103	5428	1018	3D	1Z	9012
*	0201103	5431	3	5Q	3D	9108
*	0201104	5166	293	3A	1Z	9004
*	0201104	5327	161	6N	3W	9108
*	0201104	6416	1089	3R	6J	9409
*	0201106	5833	994	2N	5Q	9010
*	**0201106**	**6419**	**586**	**7C**	**3T**	**9407**
*	0201108	5485	465	5Q	7C	9310
*	0201109	3606	211	5C	5G	9002
*	0201110	5431	1030	8B	7C	9106
*	0201110	5652	221	3T	6Q	9209
*	0201110	5670	18	3T	5Q	9312
*	**0201110**	**5696**	**26**	**3W**	**3T**	**9401**
*	0201111	5539	271	7A	7C	9107
*	0201111	5895	356	1B	7A	9209
*	0201111	6136	241	3R	1B	9312
*	0201112	5189	927	3P	5G	9007
*	0201112	5804	615	3Q	3M	9211
*	0201113	5313	262	1Z	3Q	9006
*	0201113	5335	22	2N	1Z	9103
*	0201113	5914	579	6F	3B	9207
*	0201113	6057	143	1Z	6F	9301
*	**0201113**	**6780**	**723**	**7C**	**3B**	**9404**
*	0201114	4807	1100	3M	5C	9111
*	**0201114**	**5159**	**352**	**3W**	**3A**	**9409**

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0201117	6415	15	3T	7C	9302
*** 0201117**	**6521**	**106**	**4B**	**3B**	**9306**
* 0201118	5056	67	6F	7D	9001
* 0201118	5094	0	4A	6F	9008
*** 0201118**	**5480**	**386**	**3W**	**3W**	**9109**
* 0201119	5247	0	1G	7C	9107
* 0201119	5569	322	6Q	7C	9203
*** 0201119**	**5600**	**31**	**6F**	**4P**	**9304**
* 0201120	5041	15	6N	7D	9005
* 0201120	5041	0	6Q	4A	9101
* 0201120	5464	423	3R	6Q	9305
*** 0201120**	**5494**	**30**	**3W**	**1Z**	**9402**
* 0201121	2913	1423	5Q	4M	9108
* 0201124	2360	959	1G	3Q	9106
* 0201124	2530	170	1Z	1R	9203
* 0201124	2920	390	3R	5G	9403
* 0201127	4525	294	4M	7C	9003
* 0201127	4600	75	6F	4M	9202
* 0201127	4825	225	4R	6F	9209
* 0201127	4828	3	3D	4R	9302
* 0202001	5199	1470	3T	6F	9208
* 0202003	4538	822	1G	5C	9011
* 0202003	5276	738	3R	1G	9302
* 0202003	6265	989	5Q	3R	9501
* 0202004	5774	692	3R	7C	9201
* 0202005	4762	615	1Z	3Q	8912
* 0202005	5212	450	3Q	1Z	9108
* 0202005	5317	105	1W	3Q	9201
*** 0202005**	**5975**	**658**	**7C**	**3T**	**9402**
* 0202006	6106	668	6P	7D	9309
* 0202007	2311	533	3T	7C	9206
* 0202007	2562	251	1Z	3W	9309
* 0202007	3053	491	6J	1Z	9410
* 0202008	3505	51	3Q	1Z	9107

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202009	5251	0	2N	1G	9108
* 0202009	5251	406	1G	7C	9108
* 0202009	5908	0	3B	7C	9212
* 0202009	5997	89	5Q	3B	9306
* 0202009	6390	393	6N	3B	9411
* 0202010	4107	415	1G	5C	9004
* 0202010	4406	299	3Q	3Q	9110
* 0202011	4048	358	3Q	7C	9201
* 0202011	4051	3	3R	3T	9306
* 0202012	4532	385	6E	1Z	9003
* 0202012	5812	427	6F	7D	9301
* 0202012	6559	747	6J	6F	9409
* 0202014	3663	1353	6N	7E	9212
* 0202015	4361	1327	3A	5C	9104
*** 0202015**	**5191**	**830**	**4D**	**1Z**	**9403**
* 0202016	5411	504	1Z	3R	9109
* 0202018	4135	229	1Z	3R	8912
*** 0202018**	**4405**	**270**	**3W**	**1Z**	**9304**
* 0202022	4387	40	3T	7D	9006
* 0202022	5880	640	5Q	3B	9501
* 0202023	4757	770	3P	1Z	9012
* 0202023	5504	747	5Q	3P	9204
* 0202024	3979	508	1W	7C	9002
* 0202024	4778	67	3D	7D	9105
* 0202024	4908	130	3P	3D	9202
* 0202025	5229	0	3R	5D	9102
* 0202025	5229	954	5C	1Z	9101
* 0202025	5380	151	1W	3R	9201
* 0202026	5538	516	1Z	5C	8912
*** 0202026**	**6021**	**483**	**4D**	**6P**	**9207**
* 0202027	4412	1441	3T	7K	9003
*** 0202027**	**6795**	**2383**	**7C**	**7C**	**9501**
* 0202028	4117	998	5Q	3Q	9112
* 0202028	4694	517	6Q	3T	9302
* 0202029	5509	975	2S	7C	9207

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202030	3567	688	1Z	2N	9005
* 0202030	3846	279	1Z	1Z	9010
* 0202030	4972	1126	5Q	1Z	9308
* 0202031	5534	791	6F	6Q	9007
* 0202031	5880	346	5Q	6F	9112
*** 0202031**	**6464**	**584**	**7C**	**3T**	**9303**
* 0202033	4307	1183	3A	8F	9003
* 0202033	4600	293	5C	3U	9301
* 0202034	2929	155	5W	7C	8910
* 0202034	4141	1212	3Q	5C	9204
* 0202035	3213	595	3U	7C	9102
* 0202035	3215	2	3A	3U	9110
* 0202035	3297	82	1W	3A	9202
* 0202036	6133	1066	3Q	7C	8910
* 0202036	6666	1	5Q	7D	9107
* 0202036	6786	120	2S	5Q	9112
* 0202036	7037	251	3T	2S	9208
* 0202037	4957	2	6F	7K	9002
* 0202037	5283	326	5C	3W	9403
* 0202038	3566	942	1Z	7D	9010
*** 0202038**	**4184**	**618**	**3W**	**1Z**	**9112**
* 0202042	5606	596	3R	7C	9207
* 0202042	5606	596	7K	7C	9212
* 0202042	5784	178	1T	7K	9305
* 0202045	2885	485	6J	1Z	8910
* 0202045	2929	44	3R	5C	9003
* 0202045	3008	79	5Q	3U	9109
* 0202045	3310	302	3R	7D	9208
* 0202047	3512	210	1W	1A	9302
* 0202047	3652	140	5Q	1W	9305
* 0202048	5037	424	1W	1Z	9203
* 0202048	5976	939	1Z	3T	9412
* 0202049	5186	1320	5Q	1Z	9002
* 0202049	5196	10	8P	5Q	9008
* 0202049	5468	272	5Q	6A	9108
* 0202049	6041	573	3R	5Q	9303

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202051	3605	480	3A	2N	9101
* 0202051	3989	384	6N	3R	9205
* 0202051	4118	129	5Q	6N	9210
*** 0202051**	**4688**	**570**	**4D**	**3B**	**9411**
* 0202052	4466	555	3A	7C	9206
* 0202053	5762	761	3Q	7C	9105
* 0202053	6011	249	3R	3Q	9302
* 0202053	6243	232	8F	3R	9307
* 0202054	3314	656	5C	5B	9001
* 0202054	3349	35	6F	5C	9006
* 0202054	3814	465	3M	6F	9204
* 0202055	5376	592	7L	6F	9007
* 0202055	5387	11	1W	7L	9009
*** 0202055**	**6372**	**985**	**7C**	**3T**	**9404**
* 0202056	3600	1103	3R	7C	9203
*** 0202056**	**4292**	**692**	**7C**	**3R**	**9301**
* 0202058	5065	320	4R	7D	9002
*** 0202058**	**5164**	**99**	**3W**	**4R**	**9405**
* 0202060	4917	460	6M	5D	8910
* 0202060	5339	422	3R	6A	9103
* 0202062	4464	40	1W	7C	9002
* 0202062	5027	563	3A	2N	9106
*** 0202062**	**6561**	**1534**	**7C**	**7D**	**9406**
* 0202063	3016	722	5D	8F	8911
* 0202063	3131	115	7K	3B	9008
* 0202063	3136	5	8C	7K	9103
* 0202063	3716	0	3B	7C	9401
* 0202063	3751	35	7K	3B	9403
* 0202064	5122	0	7A	7A	9001
* 0202064	5122	809	7A	5C	8912
* 0202064	5834	5	2S	7C	9401
* 0202065	3090	436	8F	7C	9203
* 0202065	3212	122	3Q	3T	9304
* 0202067	2761	1096	3P	5C	9203
*** 0202067**	**3152**	**391**	**7C**	**3P**	**9405**

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202068	4683	236	5Q	7C	9302
* 0202068	5022	338	1W	5Q	9402
* 0202069	5422	0	2Q	7K	9312
* 0202069	5422	138	7K	7D	9205
* 0202070	4390	3	5Q	7C	9201
* 0202070	5625	1235	7T	5Q	9406
* 0202071	3943	178	1W	7C	9201
* 0202072	3636	1638	5Q	1Z	8910
*** 0202072**	**4386**	**750**	**4D**	**5Q**	**9110**
* 0202074	3558	199	2N	3W	9005
* 0202074	4217	659	6Q	2N	9204
*** 0202074**	**4867**	**650**	**7C**	**3R**	**9402**
* 0202075	2865	1006	5C	3T	9010
* 0202075	4219	1354	6N	5C	9312
* 0202075	4225	0	3R	8F	9406
* 0202075	4225	6	2N	7C	9405
* 0202075	4239	14	8C	3B	9408
* 0202076	3715	83	2N	7C	9002
* 0202076	4161	327	5Q	7C	9111
* 0202078	2976	99	1Z	4D	9207
* 0202078	3057	81	3R	1Z	9307
*** 0202078**	**3439**	**382**	**7C**	**3R**	**9501**
* 0202080	5481	3	3P	7C	8911
* 0202080	5483	2	3P	3M	8912
*** 0202080**	**7223**	**1740**	**7C**	**7C**	**9407**
* 0202081	5641	1283	3R	4P	9301
* 0202083	3548	405	2C	7J	9006
* 0202083	4683	1135	1G	2C	9309
* 0202084	6540	70	1B	7D	9206
* 0202085	4858	82	1W	7D	9005
*** 0202085**	**5412**	**554**	**4D**	**3T**	**9301**
* 0202086	2080	116	3Q	3R	9003
* 0202086	2147	67	3T	2S	9009
* 0202086	2355	11	2S	5W	9302
* 0202086	2572	217	6Q	2S	9409

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202087	4339	1285	5Q	7K	9103
* 0202087	4406	67	5Q	5Q	9109
* 0202088	4828	912	3R	1G	9207
* 0202088	6054	362	6F	7C	9502
* 0202089	4435	226	7A	5C	9007
* 0202089	4442	7	7J	7J	9008
* 0202089	4971	529	3Q	7J	9202
* 0202089	4987	16	5D	6Q	9404
* 0202090	3437	0	2C	2A	9110
* 0202090	3437	376	1Z	7C	9101
*** 0202090**	**4509**	**1072**	**4B**	**2C**	**9308**
* 0202091	4062	168	1Z	7D	9012
* 0202091	4062	168	5C	7D	9103
* 0202091	4676	614	2C	6Q	9302
* 0202092	3475	228	1G	5C	9106
* 0202093	4613	703	3R	7C	9312
* 0202095	5694	89	1Z	7C	9101
* 0202096	2036	0	3B	7C	9104
* 0202096	3318	1282	6R	3B	9502
* 0202097	4905	864	3R	7C	9411
* 0202098	4246	333	7K	5Q	9008
* 0202098	4847	601	8B	7K	9110
* 0202101	4326	852	3A	3Q	9002
* 0202101	5186	860	1Z	3A	9303
* 0202101	5229	43	3R	3B	9305
* 0202101	5477	248	6F	3R	9403
* 0202102	4727	921	3A	5C	9003
* 0202102	5527	800	8C	3A	9311
* 0202103	2550	0	8B	7A	9409
* 0202106	2374	0	7J	7C	9010
* 0202106	2867	493	5Q	3B	9107
* 0202106	3395	528	4D	5Q	9406
* 0202107	1273	74	3R		9003
* 0202107	1305	32	6K	3R	9107
*** 0202107**	**2327**	**1022**	**7D**	**6K**	**9403**

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202108	5255	340	1W	3R	9406
*** 0202108**	**5637**	**382**	**7C**	**3B**	**9501**
* 0202109	5232	1443	6N	2N	9501
* 0202111	5749	995	5C	7C	9309
* 0202113	4165	382	1Z	5Q	9008
* 0202113	5051	886	7K	1Z	9206
* 0202116	5367	337	7K	7D	9306
* 0202117	3939	1042	5Q	1W	9105
* 0202117	4513	25	3R	7C	9501
* 0202119	4607	1497	3P	7K	9401
* 0202119	4681	74	3D	3P	9406
* 0202120	2920	660	5C	7C	8912
* 0202120	2994	74	8P	5C	9008
* 0202120	3405	411	3T	3B	9203
*** 0202120**	**4254**	**849**	**7D**	**3T**	**9402**
* 0202121	5854	338	3A	7C	9111
* 0202122	4950	814	5Q	2N	9010
* 0202122	5234	284	8F	5Q	9212
* 0202123	6375	266	3T	7D	9502
* 0202125	5802	704	7L	1Z	8912
* 0202125	6418	616	1Z	7L	9110
* 0202126	6789	1152	3T	5Q	9307
* 0202127	5584	291	1Z	5G	8911
* 0202127	5830	246	1Z	1Z	9008
* 0202127	5990	160	3Q	1Z	9102
* 0202127	6790	960	7K	1Z	9209
* 0202128	4375	557	1Z	5C	9103
* 0202128	4955	580	6N	7C	9311
* 0202130	5239	681	1Z	3T	9102
* 0202130	7004	84	3T	7C	9404
* 0202131	4540	404	3Q	7C	9003
* 0202131	6129	998	2N	7D	9304
* 0202132	5510	1490	3R	2N	9303
* 0202133	3777	560	1Z	3R	9102
*** 0202133**	**4369**	**592**	**7C**	**1Z**	**9406**

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202134	5203	1115	3Q	7K	9101
*** 0202134**	**5887**	**684**	**7C**	**7C**	**9409**
* 0202137	4753	916	1Z	4D	9003
* 0202137	4848	115	5W	1Z	9105
* 0202137	5359	3	3P	3B	9212
* 0202137	5361	0	3P	3B	9303
* 0202137	5361	0	3P	3P	9307
* 0202137	5361	0	3P	3B	9311
* 0202137	5361	2	3P	3P	9302
* 0202138	4726	1389	5Q	7C	9206
* 0202138	4766	40	5Q	3B	9401
* 0202138	5168	402	6B	5Q	9410
* 0202139	4658	404	5Q	3Q	9007
*** 0202139**	**4938**	**280**	**3W**	**7C**	**9501**
* 0202140	2564	393	3A	7C	9011
* 0202141	4557	242	6F	7C	9105
* 0202141	4946	389	3A	6F	9207
* 0202142	5726	850	2N	8F	9102
* 0202142	6080	354	2A	2N	9210
*** 0202142**	**6285**	**205**	**3W**	**5C**	**9406**
* 0202143	5175	1026	3P	7C	9202
*** 0202143**	**6424**	**1249**	**7C**	**3B**	**9501**
* 0202146	3518	892	5Q	2N	9010
* 0202146	3573	55	1W	3Q	9404
* 0202146	3575	2	7K	3B	9302
* 0202147	5165	761	2F	5C	9110
* 0202147	5555	390	2F	6F	9303
* 0202149	4595	485	3A	7C	9003
* 0202149	5745	1150	3R	3W	9312
* 0202150	6417	0	1W	7C	9201
*** 0202150**	**7042**	**625**	**3W**	**6N**	**9410**
* 0202151	4353	467	5D	3P	9003
* 0202151	4906	553	7A	5D	9110
*** 0202151**	**5302**	**396**	**3W**	**4M**	**9410**
* 0202154	5606	859	5C	7C	9210

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202155	4072	143	1Z	7C	9008
* 0202155	4836	59	3B	3W	9407
* 0202156	6631	0	6A	5W	9309
* 0202156	6631	90	5W	3B	9207
* 0202156	6739	108	5W	5W	9412
* 0202157	3418	212	8B	7G	9111
* 0202157	4566	1148	5Q	8B	9411
* 0202158	5234	202	3Q	5C	8912
* 0202158	5522	288	2N	3B	9303
* 0202160	4784	567	8P	7C	9106
* 0202160	4818	34	3T	5W	9108
* 0202160	4880	62	5Q	3T	9110
*** 0202160**	**5754**	**874**	**7C**	**5Q**	**9410**
* 0202161	4515	653	1Z	3W	9005
* 0202161	5472	957	3Q	1Z	9302
* 0202163	3395	380	3R	7C	9306
* 0202164	5017	337	3A	7C	9004
* 0202164	6124	1107	1Z	3A	9210
* 0202164	6622	498	4R	3B	9401
*** 0202164**	**6852**	**230**	**3W**	**4R**	**9408**
* 0202166	4009	250	3Q	7C	9106
* 0202166	5124	1115	3B	3Q	9311
* 0202167	4022	937	1W	5Q	9201
* 0202167	4492	470	5Q	3T	9304
* 0202167	4898	406	1T	5Q	9401
*** 0202167**	**4923**	**25**	**4D**	**1T**	**9407**
* 0202168	608	0	3R	4D	9401
* 0202169	4511	0	5Q	5Q	8911
* 0202169	4625	114	1Z	5Q	9012
* 0202169	6178	1011	6N	6A	9311
* 0202171	4182	362	3A	7K	9002
* 0202171	4660	478	7K	3A	9107
* 0202171	4974	314	1Z	7K	9209
* 0202171	4994	20	8F	1Z	9210
* 0202171	5063	69	2N	8F	9306
* 0202172	5743	355	3R	7D	9404

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202173	3010	1030	5Q	2C	9012
* 0202173	3300	290	5Q	5Q	9110
* 0202173	3365	65	3T	5Q	9203
* 0202173	4089	724	3R	3T	9405
* 0202174	5997	1360	5C	7C	9104
*** 0202174**	**7244**	**1247**	**7C**	**3T**	**9412**
* 0202176	4008	11	2N	1Z	8912
*** 0202176**	**4607**	**599**	**3W**	**2N**	**9109**
* 0202178	5254	1062	5C	4D	9106
*** 0202178**	**5853**	**599**	**3W**	**5C**	**9311**
* 0202179	4201	101	3M	3W	9302
* 0202181	5997	1513	5Q	7C	9102
* 0202181	6927	930	8B	5Q	9205
*** 0202181**	**7630**	**703**	**7C**	**6F**	**9403**
* 0202182	6570	1336	3M	7C	9205
* 0202182	6822	252	1Z	7C	9405
* 0202183	5624	1430	1Z	5C	9109
*** 0202183**	**7209**	**1585**	**4D**	**1Z**	**9409**
* 0202185	3979	0	2A	3Q	9001
* 0202185	5221	0	8B	3R	9412
* 0202185	5221	1242	3R	5D	9303
* 0202186	4357	381	2N	1Z	9005
* 0202186	4361	4	5Q	7C	9107
* 0202186	4459	98	3A	5Q	9112
* 0202186	5228	157	3T	7C	9412
* 0202188	5474	1373	2N	5C	9009
* 0202188	6122	648	1Z	2N	9108
* 0202189	5280	652	5Q	7C	9304
*** 0202189**	**5436**	**156**	**3W**	**5Q**	**9405**
* 0202192	5169	1932	2N	5C	9202
* 0202192	5867	698	1Z	1W	9305
*** 0202192**	**6033**	**166**	**7C**	**1Z**	**9411**
* 0202195	4615	727	7K	7C	9207
* 0202196	4275	1105	5W	3D	9204
*** 0202196**	**4778**	**503**	**3W**	**3T**	**9405**

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202197	5577	1116	3Q	7K	9201
* 0202197	5766	189	3R	7D	9208
* 0202201	4643	1482	5Q	6A	9005
* 0202201	5568	925	5Q	5Q	9211
* 0202203	3448	679	1Z	3Q	9007
* 0202203	3495	47	5W	1Z	9101
* 0202203	4823	496	3T	7C	9312
* 0202204	5260	804	5B	2S	9012
* 0202204	6388	1128	2Q	5B	9409
* 0202205	4933	914	1Z	5G	9101
* 0202205	5163	230	8F	1Z	9206
* 0202206	3892	57	3P	3P	9001
* 0202206	5359	30	3T	6A	9412
* 0202207	5319	434	1Z	5Q	9006
*** 0202207**	**6793**	**1474**	**7C**	**1Z**	**9311**
* 0202208	4624	688	6Q	5B	9003
* 0202208	4649	25	3R	6Q	9009
* 0202208	5348	699	8B	3Q	9308
* 0202209	4521	0	3R	6P	9104
* 0202209	4521	401	6P	7C	9005
*** 0202209**	**5335**	**814**	**5G**	**3R**	**9302**
* 0202210	4294	1170	1A	5G	9311
* 0202210	4489	195	5C	1A	9406
* 0202211	3413	62	3U	8F	9001
* 0202211	4099	218	1Z	7D	9205
* 0202211	4489	390	7A	1Z	9302
* 0202212	5383	320	2N	7C	9201
* 0202212	5881	498	3R	2N	9411
* 0202213	5521	1316	6F	1Z	9008
* 0202213	5868	347	1A	3B	9301
* 0202214	5431	459	3T	7D	9201
* 0202217	5282	323	6J	7C	9104
* 0202217	5476	194	3B	6K	9111
*** 0202217**	**6422**	**946**	**7C**	**3P**	**9305**
* 0202219	4854	785	3R	5G	9109
*** 0202219**	5426	572	7C	3R	9311

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202220	2913	315	1Z	1Z	9001
* 0202220	3029	116	3M	1Z	9012
* 0202220	3760	731	8F	7C	9306
*** 0202220**	**3774**	**14**	**4D**	**8F**	**9407**
* 0202223	6509	0	6J	3T	9001
* 0202223	6626	117	3R	6Y	9005
* 0202223	7040	414	3A	3R	9210
* 0202223	7140	100	3T	3R	9407
* 0202224	5164	902	1Z	3Q	9101
* 0202224	5764	600	3R	1Z	9307
* 0202225	7240	1092	7A	7D	9305
* 0202226	3405	361	3A	3W	9005
* 0202226	4554	1149	3T	3A	9306
* 0202227	5467	958	1Z	7H	9103
* 0202227	5667	200	6N	3Q	9306
* 0202227	5927	460	3R	3Q	9406
* 0202228	5768	817	6F	3W	9203
* 0202228	5868	100	7A	6F	9209
* 0202229	3871	399	5Q	3Q	8910
* 0202229	4097	226	1W	5Q	9203
* 0202231	4851	1179	3A	7K	9105
* 0202231	5378	527	3R	3R	9304
* 0202232	5412	1514	3A	1Z	9101
* 0202232	6418	1007	5Q	3R	9212
* 0202233	5394	1370	1W	3Q	9003
* 0202233	5439	45	5D	3T	9008
* 0202233	5634	195	8C	3Q	9105
* 0202234	3815	190	1Z	1Z	9012
* 0202234	4121	306	1W	3W	9110
* 0202234	4206	85	5Q	3T	9205
* 0202235	5045	832	2S	3R	9101
* 0202235	5050	1	5Q	3D	9205
*** 0202235**	**5780**	**730**	**3W**	**5Q**	**9410**
* 0202236	5812	1350	7J	7D	9008
* 0202236	7010	1198	3T	1B	9405

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202237	4470	66	2S	7C	8912
*** 0202237**	**5241**	**771**	**7C**	**2S**	**9106**
* 0202239	4367	896	5W	5C	9012
* 0202239	4595	228	9J	5W	9207
* 0202239	5286	691	6F	9J	9310
* 0202241	4777	510	3A	7C	9201
* 0202241	4981	204	5Q	8B	9309
* 0202241	5365	384	3T	6A	9411
* 0202242	6240	1456	1Z	7C	9310
* 0202244	4892	401	4P	3D	9301
* 0202245	4226	0	2S	7C	8912
*** 0202245**	**4275**	**49**	**3W**	**2S**	**9106**
* 0202247	3621	879	3Q	7C	9005
*** 0202247**	**5124**	**1503**	**7C**	**6P**	**9405**
* 0202248	4340	865	1Z	7K	9205
* 0202248	5183	843	7K	1Z	9410
* 0202250	4946	733	5Q	7C	9012
* 0202250	5015	69	5Q	5Q	9103
* 0202251	2661	169	4P	4B	9312
* 0202252	4334	1447	3R	7K	9304
*** 0202252**	**4337**	**3**	**3W**	**3R**	**9412**
* 0202254	5922	149	5Q	7C	9202
*** 0202254**	**6670**	**748**	**3W**	**5Q**	**9408**
* 0202256	5258	216	6J	7D	9208
* 0202257	6791	790	3T	7C	9304
*** 0202257**	**6796**	**5**	**3W**	**3T**	**9312**
* 0202259	3098	304	1Z	1Z	8911
* 0202259	3994	896	3Q	1Z	9201
*** 0202259**	**4452**	**458**	**4D**	**1T**	**9312**
* 0202260	5618	1175	8C	7C	9010
* 0202260	6536	918	1Z	7C	9302
* 0202260	6901	0	7K	3T	9403
* 0202260	6901	0	6R	7K	9502
* 0202260	6901	365	3T	1Z	9401
* 0202261	5025	436	2S	3Q	9007
* 0202261	6696	1212	1W	7D	9402

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202262	5036	0	3W	6F	9201
* 0202262	5036	696	3Q	3P	8911
* 0202262	5445	409	3M	3P	9302
* 0202262	5446	1	3P	3B	9303
* 0202263	5772	530	1Z	7C	9109
*** 0202263**	**6402**	**630**	**7C**	**1Z**	**9312**
* 0202264	4124	78	3Q	3B	9104
* 0202264	5453	227	3R	7C	9409
* 0202265	4522	667	5Q	7K	9210
* 0202265	4890	368	5Q	3B	9310
* 0202265	5161	271	5Q	7K	9407
* 0202266	3218	882	3P	4J	9006
* 0202266	3557	339	1G	3B	9104
*** 0202266**	**3731**	**174**	**4D**	**4P**	**9305**
* 0202267	5742	385	3Q	4M	9001
* 0202267	5753	11	7K	6P	9108
* 0202267	6593	840	3R	3T	9406
* 0202268	5627	1199	1Z	3R	9204
* 0202269	3912	332	5Q	7C	9102
* 0202269	4479	567	6Q	5Q	9303
* 0202271	5791	20	5C	3W	9004
* 0202271	5990	199	5Q	5C	9108
*** 0202271**	**7211**	**1221**	**7C**	**5Q**	**9402**
* 0202272	3895	0	3Q	7C	9001
* 0202272	5712	883	3R	7D	9405
* 0202272	5904	192	1Z	3R	9409
* 0202273	5078	1291	3A	3W	9201
* 0202274	3766	246	1G	7C	9402
* 0202276	6324	439	3R	7C	9406
* 0202278	5425	946	2N	7C	9002
* 0202278	5470	45	3Q	2N	9005
* 0202278	5485	15	8F	3Q	9104
*** 0202278**	**6554**	**1069**	**4D**	**7C**	**9410**
* 0202280	3762	355	3A	7C	9110
* 0202280	3968	206	6F	3A	9210
* 0202280	4499	0	2F	6A	9411

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

	Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
*	0202281	4928	1555	3A	5Q	9002
*	0202281	4939	11	8P	3A	9008
*	0202281	5954	1015	1Z	6A	9204
*	**0202281**	**6295**	**341**	**7C**	**3B**	**9407**
*	0202282	5246	2	4P	3R	8912
*	0202282	6497	0	3R	7C	9406
*	**0202282**	**6497**	**1251**	**7C**	**4P**	**9405**
*	0202283	3718	570	2S	7C	9102
*	0202283	3725	7	5W	3B	9109
*	0202283	4243	518	3A	5W	9302
*	0202284	4160	399	2N	5C	9109
*	**0202284**	**4901**	**741**	**3W**	**7D**	**9407**
*	0202285	5401	1249	3D	1Z	9208
*	0202285	6771	1370	5C	3D	9410
*	0202286	1868	0	7K	1Z	8911
*	**0202286**	**2647**	**779**	**7C**	**3D**	**9402**
*	0202288	4211	934	3T	5G	9305
*	0202288	4696	485	1W	5Q	9404
*	0202289	5497	661	8F	4B	9403
*	0202290	4214	422	3R	7D	9102
*	0202290	4585	371	3Q	3R	9201
*	0202290	4812	227	5Q	3Q	9301
*	0202290	5430	618	5Q	5Q	9412
*	0202291	4146	816	3R	7C	9005
*	0202291	5302	1153	1W	5C	9406
*	0202292	6532	802	5W	7D	9309
*	0202293	4634	438	1Z	8F	9006
*	0202293	4788	154	1Z	1Z	9012
*	0202293	5399	611	5Q	1Z	9405
*	0202294	3863	988	5Q	7C	8910
*	0202294	4063	200	5Q	5Q	9201
*	0202294	4750	887	6N	5Q	9303
*	0202296	5268	778	5B	4P	9103
*	0202296	5765	1275	8F	4P	9205
*	**0202296**	**5788**	**23**	**3W**	**2N**	**9403**
*	0202297	5190	492	1W	7C	9201

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202298	4227	521	3M	2N	9206
* 0202298	4295	68	3A	7D	9301
* 0202299	5315	483	6F	5G	9002
* 0202299	5795	480	7K	6F	9110
*** 0202299**	**6862**	**1067**	**7C**	**1T**	**9408**
* 0202300	3956	862	1Z	2S	9101
* 0202300	4363	407	3D	1Z	9110
*** 0202300**	**5414**	**1051**	**7C**	**3D**	**9407**
* 0202301	3042	1007	7K	7D	9206
* 0202301	3196	154	6N	3B	9307
*** 0202301**	**3714**	**518**	**3W**	**6N**	**9407**
* 0202302	5082	211	1G	5C	9006
* 0202304	3304	290	1Z	7C	9006
* 0202304	4322	771	2N	7D	9311
* 0202305	4349	391	3Q	6F	9010
* 0202305	5087	738	5Q	5C	9209
* 0202306	3383	113	1Z	1Z	9001
* 0202306	3921	538	3D	1Z	9108
* 0202306	4377	456	1Z	7C	9402
* 0202307	5843	1157	3Q	7C	9208
* 0202308	4269	0	2Q	2C	9107
* 0202308	4541	272	1Z	2Q	9206
* 0202308	4724	183	5W	1Z	9405
* 0202311	3752	27	5C	3R	9004
*** 0202311**	**4370**	**618**	**4D**	**5C**	**9404**
* 0202312	3465	216	6Q	7C	9103
* 0202312	4022	557	2N	3Q	9304
* 0202313	6150	391	7E	7D	9409
* 0202315	4097	357	3T	7C	9011
* 0202315	4492	241	6N	3B	9406
* 0202317	4173	373	8B	7C	9110
* 0202317	4238	65	1W	3R	9203
* 0202317	4318	80	5C	1W	9208
* 0202319	4970	268	1Z	1Z	9003
* 0202319	5303	333	3B	1Z	9109
* 0202319	5638	335	5Q	5Q	9210

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202321	4974	529	7K	7C	9205
* 0202321	5074	99	1Z	3T	9209
* 0202322	4100	189	5Q	7C	9009
* 0202322	5098	998	1Z	5Q	9303
* 0202322	5675	577	5W	1Z	9409
* 0202323	4638	392	8P	8C	9009
*** 0202323**	**5750**	**1112**	**7C**	**8P**	**9402**
* 0202324	3986	860	5C	8F	8911
*** 0202324**	**4750**	**764**	**3W**	**3Q**	**9201**
* 0202325	5554	1056	8F	7D	9401
* 0202326	4403	448	3A	7K	9002
* 0202326	5083	3	3T	7D	9203
*** 0202326**	**5406**	**323**	**4B**	**1W**	**9308**
* 0202327	6609	513	4R	7D	9209
* 0202327	6781	172	7K	4R	9305
* 0202328	2225	394	3R	7C	9001
* 0202328	3381	635	5C	7C	9412
* 0202330	5157	662	1Z	7C	9011
* 0202331	3163	0	4A	3A	9008
* 0202331	3163	421	3A	5D	9003
* 0202331	4214	259	1Z	7C	9212
* 0202333	4442	1121	5Q	7C	9201
* 0202333	4966	524	8B	5Q	9304
* 0202333	5292	326	3T	7C	9312
* 0202334	5644	213	2N	7D	9303
* 0202336	4776	179	8F	5Q	8910
* 0202336	5155	15	3Q	7C	9104
* 0202336	5380	225	3A	3Q	9208
* 0202338	3678	0	7K	7C	9001
* 0202338	3987	309	8C	7K	9010
* 0202338	4494	507	2C	2C	9304
* 0202339	6364	470	3P	7D	9410

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202340	4595	227	5W	5C	9101
* 0202340	4615	20	2P	5W	9103
* 0202340	4619	4	1W	4B	9112
* 0202340	4860	221	3M	3T	9301
*** 0202340**	**5413**	**553**	**7C**	**3P**	**9411**
* 0202342	2825	42	6T	7E	9005
* 0202342	2827	2	7K	6T	9101
* 0202342	3497	0	2A	5Q	9208
* 0202342	3497	670	5Q	7K	9205
* 0202342	3540	43	3R	5Q	9306
* 0202343	5630	893	3T	3R	9204
* 0202345	5658	1413	3R	7C	9307
* 0202346	4315	1	5W	5W	9101
* 0202346	4314	19	5W	7C	9008
* 0202346	4799	484	3Q	5W	9206
* 0202347	3610	492	2N	7C	9011
* 0202347	4196	586	6Q	2N	9206
* 0202348	4555	96	7K	5D	9003
* 0202348	5945	1390	3R	7K	9409
* 0202351	5172	1097	8C	1G	9207
* 0202351	6349	1177	1T	8C	9407
* 0202353	5541	1062	3Q	7C	9203
* 0202353	6591	1050	1G	3Q	9402
* 0202354	4883	1450	1Z	6F	9011
* 0202354	5488	605	8F	1Z	9205
*** 0202354**	**6593**	**1105**	**7C**	**1W**	**9408**
* 0202355	4491	1	3Q	7C	9005
* 0202355	5522	1031	7K	3Q	9209
* 0202355	5904	382	1Z	7C	9409
* 0202356	4456	581	3Q	7C	8910
* 0202356	4658	202	1G	5D	9004
* 0202356	4973	315	4D	6Q	9201
* 0202356	4973	315	1Z	6Q	9202
* 0202356	5772	799	3T	1Z	9407
* 0202356	5801	29	3T	3T	9501
* 0202358	5207	310	8P	7C	9212

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202359	4736	355	8C	7D	9009
* 0202359	4748	12	3T	5D	9101
*** 0202359**	**6137**	**1389**	**7C**	**3T**	**9404**
* 0202360	3352	193	3W	1Z	9001
* 0202360	3546	387	3P	1Z	9006
* 0202360	4101	555	3R	3W	9303
* 0202361	3295	484	1W	7C	9001
*** 0202361**	**4365**	**1070**	**7C**	**7K**	**9207**
* 0202362	4576	819	3Q	3R	9208
* 0202363	4001	888	1Z	5C	9004
* 0202363	4280	279	7K	1Z	9012
* 0202363	5024	274	5Q	7C	9209
* 0202363	5610	586	5C	3B	9411
* 0202364	5343	1084	6J	2N	9104
* 0202364	5395	52	5Q	7D	9111
* 0202364	5398	55	5Q	7D	9112
* 0202365	6022	745	6J	8C	9104
* 0202365	6362	340	6N	6J	9203
* 0202365	6385	23	1A	3A	9306
* 0202366	4428	56	2C	5D	9007
* 0202366	4968	540	5Q	3Q	9201
* 0202367	4118	46	8C	1Z	9005
* 0202367	4201	83	1G	8C	9104
* 0202368	3690	176	5C	7C	8910
* 0202368	4447	757	1W	5C	9201
*** 0202368**	**5225**	**778**	**7C**	**3T**	**9409**
* 0202369	5314	299	3Q	7D	9303
*** 0202369**	**5323**	**9**	**4D**	**7A**	**9406**
* 0202370	4750	263	6F	3R	8911
* 0202370	5368	618	3T	6F	9012
*** 0202370**	**6407**	**1039**	**3W**	**7C**	**9404**
* 0202373	3958	333	1G	7C	9003
* 0202373	4975	63	3T	7C	9307
* 0202373	5046	71	3R	3T	9411

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202374	3838	1018	5Q	3W	9108
* 0202374	3870	32	5Q	5Q	9206
*** 0202374**	**4841**	**971**	**3W**	**3B**	**9406**
* 0202375	5367	806	6P	1Z	9109
* 0202375	5946	579	3T	3T	9411
* 0202376	5435	188	8C	7D	9205
*** 0202376**	**6017**	**582**	**3W**	**8C**	**9501**
* 0202377	4178	477	3P	3Q	9104
* 0202377	4178	0	7K	3P	9107
* 0202377	4469	291	2S	1G	9202
*** 0202377**	**5539**	**1070**	**7C**	**7D**	**9405**
* 0202378	4138	230	3Q	5Q	9006
* 0202378	5079	941	3Q	3Q	9210
*** 0202378**	**6199**	**1120**	**7C**	**3B**	**9502**
* 0202379	3804	1617	1C	3Q	9006
*** 0202379**	**4584**	**475**	**7C**	**7D**	**9409**
* 0202380	4716	953	1Z	5D	9005
* 0202380	5144	428	8P	1Z	9106
* 0202380	5910	766	6E	3T	9412
* 0202383	4488	704	1Z	7L	9003
* 0202383	4497	9	6F	1Z	9104
* 0202384	4630	1218	2N	1Z	9201
* 0202384	4902	272	7K	1W	9211
*** 0202384**	**6239**	**1337**	**7C**	**7C**	**9501**
* 0202385	4840	786	7K	7D	9405
* 0202386	4520	126	1Z	1Z	8910
* 0202386	4539	19	2A	1Z	9006
* 0202386	5726	1187	3B	4B	9409
* 0202388	4824	638	1Z	7D	9401
* 0202390	4825	347	7A	7C	9002
*** 0202390**	**5679**	**854**	**7C**	**3D**	**9201**
* 0202391	3575	417	4P	3Q	9105
* 0202391	4207	632	7K	4A	9306
* 0202391	4628	421	5D	7K	9408
* 0202392	2619	55	3R	1Z	9003

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202393	4800	667	1Z	7L	8911
* 0202393	5032	232	6J	1Z	9207
* 0202393	5037	237	3D	1Z	9411
* 0202393	5040	3	3D	3D	9501
* 0202394	3561	1063	2N	7C	9204
* 0202394	3800	239	1Z	1W	9309
* 0202397	2146	215	3T	3Q	9008
* 0202397	3119	973	3R	3T	9312
* 0202398	4720	1598	3R	7C	9102
* 0202398	4898	178	5Q	3R	9201
* 0202398	5212	492	3R	3R	9307
* 0202399	3930	291	6N	6F	9003
*** 0202399**	**5106**	**1176**	**7C**	**7C**	**9502**
* 0202400	5271	808	6N	7D	9310
* 0202401	4167	305	3A	7D	8911
* 0202401	4803	26	3P	7C	9108
* 0202401	4855	52	3R	3B	9203
*** 0202401**	**5842**	**987**	**7C**	**7D**	**9402**
* 0202402	5027	2128	1Z	3Q	9003
* 0202402	5474	447	8F	3U	9207
* 0202402	5671	197	2S	2N	9406
* 0202403	4299	1165	3T	7D	8911
* 0202403	5027	728	3R	3Q	9201
*** 0202403**	**5937**	**910**	**3W**	**3R**	**9410**
* 0202404	5064	509	5B	7C	9102
* 0202404	5107	43	2N	5B	9204
* 0202405	3679	240	2N	3B	9210
*** 0202405**	**3768**	**89**	**3W**	**7D**	**9401**
* 0202406	3635	830	1Z	5C	9108
* 0202406	3650	15	7K	1Z	9204
* 0202406	4216	566	1Z	7K	9308
* 0202406	4430	214	6F	1Z	9406
* 0202407	6998	273	5Q	7D	9410
* 0202409	5098	691	8B	6Q	9111
* 0202409	5845	747	7L	8B	9405

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202410	4463	1176	3A	3Q	9003
* 0202410	5639	3	3T	3B	9304
*** 0202410**	**5765**	**126**	**3W**	**3T**	**9410**
* 0202412	4616	1613	3A	7K	9102
*** 0202412**	**5773**	**1157**	**3W**	**3R**	**9407**
* 0202413	5031	523	1Z	7C	9309
* 0202413	5033	2	3B	3B	9312
* 0202415	4755	435	6C	1Z	9106
* 0202416	4863	387	6J	7C	9501
* 0202417	4806	1164	3A	7C	8911
*** 0202417**	**6405**	**1599**	**7C**	**3A**	9208
* 0202419	1873	686	1W	7C	8910
* 0202419	1921	48	1W	1W	9001
* 0202419	2413	492	6N	1W	9202
* 0202420	4405	226	7K	5C	8910
* 0202420	4899	494	6F	3Q	9104
*** 0202420**	**5830**	**931**	**7C**	**6F**	**9312**
* 0202421	4244	798	5Q	7D	9302
*** 0202421**	**4301**	**57**	**3W**	**5Q**	**9401**
* 0202423	4232	1399	5C	6Q	9011
*** 0202423**	**4393**	**161**	**3W**	**5C**	**9111**
* 0202424	4268	785	9C	7C	9106
* 0202424	4511	243	1W	7D	9201
* 0202424	4980	469	5W	2N	9303
* 0202426	5476	1008	3T	7C	9108
* 0202426	5523	47	3A	3T	9211
* 0202427	4540	345	2N	1Z	9102
* 0202427	5253	13	1G	7C	9502
* 0202428	3119	162	3Q	3Q	9004
* 0202428	3635	516	6Q	3Q	9210
* 0202431	3949	441	1G	5G	9105
*** 0202431**	**4134**	**185**	**3W**	**1R**	**9111**
* 0202432	4527	1379	3Q	5D	9104
* 0202432	4573	46	1Z	5D	9111
* 0202433	3892	1157	3A	5Q	9111

APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Reason for Removal	Prior Removal Reason	Start Date
* 0202437	4948	313	6F	5D	9008
* 0202437	5018	70	3R	6F	9102
* 0202437	5398	380	3R	3R	9306
* 0202438	5418	1419	5W	5C	9207
*** 0202438**	**5574**	**156**	**3W**	**2N**	**9407**
* 0202439	4403	811	3Q	6O	9001
* 0202439	4552	149	1Z	3Q	9012
* 0202439	5405	853	6F	1Z	9402
* 0202440	4588	116	4P	6Q	9003
* 0202440	5149	561	7A	4P	9202
*** 0202440**	**5892**	**743**	**7C**	**5C**	**9409**
* 0202441	4799	0	5Q	5G	8911
* 0202441	5946	559	1Z	7C	9310
* 0202442	5080	1279	1G	6Q	9209
* 0202443	5347	1362	3A	5C	9212
* 0202443	5445	98	7K	3R	9311
* 0202443	5642	197	7J	7K	9406
* 0202444	4656	37	1Z	7D	9009
* 0202444	4660	4	1Z	1Z	9101
* 0202444	5171	511	5W	1Z	9201
*** 0202444**	**6188**	**1017**	**7C**	**5W**	**9311**

APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

A. CONTENTS OF APPENDIX B

Appendix B contains all of the fail times and residual operating times as derived from Appendix A. They are indexed in sequential order. There are 684 true failure times after removing the "zero" entries. There are 106 residual operating times. These are the times used in the Weivull analysis in Chapter II.

APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
1	1	47	18	93	57	139	113	185	195
2	1	48	19	94	59	140	114	186	197
3	1	49	19	95	62	141	115	187	197
4	1	50	20	96	62	142	115	188	199
5	1	51	20	97	63	143	116	189	199
6	2	52	20	98	65	144	116	190	200
7	2	53	20	99	65	145	116	191	200
8	2	54	22	100	66	146	117	192	202
9	2	55	23	101	67	147	120	193	202
10	2	56	25	102	67	148	122	194	204
11	2	57	25	103	67	149	126	195	206
12	2	58	26	104	67	150	129	196	210
13	2	59	27	105	68	151	130	197	211
14	3	60	29	106	69	152	138	198	211
15	3	61	30	107	69	153	140	199	212
16	3	62	31	108	70	154	143	200	213
17	3	63	32	109	70	155	143	201	214
18	3	64	32	110	71	156	149	202	215
19	3	65	33	111	74	157	149	203	216
20	3	66	34	112	74	158	151	204	216
21	3	67	35	113	74	159	154	205	217
22	3	68	35	114	75	160	154	206	218
23	4	69	37	115	78	161	155	207	221
24	4	70	39	116	79	162	157	208	221
25	4	71	40	117	80	163	160	209	225
26	5	72	40	118	81	164	161	210	225
27	5	73	40	119	82	165	162	211	226
28	6	74	42	120	82	166	163	213	226
29	7	75	43	121	83	167	168	214	226
30	7	76	43	122	83	168	168	215	227
31	9	77	43	123	84	169	169	216	227
32	10	78	44	124	85	170	170	217	227
33	11	79	45	125	88	171	172	218	228
34	11	80	45	126	89	172	176	219	228
35	11	81	46	127	89	173	178	220	229
36	11	82	46	128	90	174	178	221	230
37	11	83	47	129	96	175	178	222	230
38	12	84	47	130	98	176	179	223	232
39	13	85	48	131	98	177	183	224	232
40	14	86	51	132	99	178	188	225	236
41	15	87	52	133	99	179	189	226	237
42	15	88	52	134	100	180	189	227	239
43	15	89	55	135	100	181	190	228	240
44	15	90	55	136	101	182	192	229	241
45	15	91	55	137	105	183	193	230	241
46	16	92	56	138	108	184	194	231	242

APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
232	243	278	315	324	385	370	456	416	527
233	246	279	320	325	385	371	459	417	528
234	246	280	320	326	387	372	460	418	529
235	248	281	322	327	387	373	460	419	529
236	249	282	323	328	389	374	465	420	530
237	250	283	326	329	390	375	465	421	533
238	251	284	326	330	390	376	467	422	538
239	251	285	327	331	391	377	469	423	540
240	252	286	332	332	391	378	470	424	553
241	259	287	333	333	392	379	470	425	555
242	262	288	333	334	393	380	477	426	555
243	263	289	333	335	394	381	478	427	557
244	266	290	335	336	399	382	480	428	557
245	268	291	337	337	399	383	480	429	559
246	271	292	337	338	401	384	482	430	560
247	271	293	338	339	401	385	483	431	561
248	272	294	338	340	402	386	484	432	563
249	272	295	339	341	404	387	484	433	566
250	272	296	340	342	404	388	485	434	567
251	273	297	340	343	405	389	485	435	567
252	274	298	345	344	406	390	485	436	570
253	279	299	346	345	406	391	490	437	573
254	279	300	347	346	407	392	491	438	577
255	284	301	347	347	409	393	492	439	579
256	288	302	354	348	411	394	492	440	579
257	290	303	355	349	414	395	492	441	580
258	290	304	355	350	415	396	492	442	581
259	291	305	355	351	417	397	493	443	586
260	291	306	356	352	421	398	494	444	586
261	291	307	357	353	421	399	496	445	592
262	293	308	358	354	422	400	498	446	595
263	293	309	361	355	422	401	498	447	596
264	294	310	362	356	423	402	504	448	596
265	299	311	362	357	424	403	507	449	600
266	299	312	365	358	427	404	508	450	601
267	301	313	368	359	428	405	509	451	605
268	302	314	371	360	434	406	510	452	609
269	304	315	373	361	435	407	511	453	611
270	305	316	376	362	436	408	513	454	614
271	306	317	380	363	436	409	516	455	615
272	309	318	380	364	438	410	516	456	615
273	310	319	381	365	439	411	517	457	616
274	310	320	382	366	441	412	518	458	618
275	313	321	382	367	447	413	521	459	618
276	314	322	384	368	448	414	523	460	632
277	315	323	384	369	450	415	524	461	635

APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
462	638	508	771	554	914	600	1066	646	1291
463	640	509	778	555	916	601	1084	647	1316
464	648	510	785	556	918	602	1089	648	1320
465	652	511	785	557	921	603	1092	649	1327
466	653	512	786	558	925	604	1096	650	1336
467	656	513	790	559	927	605	1097	651	1350
468	659	514	791	560	930	606	1100	652	1353
469	660	515	798	561	934	607	1103	653	1354
470	661	516	799	562	937	608	1105	654	1360
471	662	517	800	563	939	609	1107	655	1362
472	667	518	802	564	941	610	1115	656	1370
473	667	519	804	565	942	611	1115	657	1370
474	668	520	806	566	946	612	1116	658	1373
475	670	521	808	567	953	613	1121	659	1379
476	679	522	809	568	954	614	1126	660	1389
477	681	523	811	569	957	615	1128	661	1390
478	685	524	814	570	958	616	1135	662	1399
479	686	525	816	571	959	617	1148	663	1413
480	688	526	817	572	960	618	1149	664	1419
481	688	527	819	573	973	619	1150	665	1423
482	691	528	822	574	975	620	1152	666	1430
483	691	529	830	575	988	621	1153	667	1441
484	692	530	832	576	989	622	1157	668	1443
485	696	531	840	577	994	623	1157	669	1447
486	698	532	843	578	995	624	1164	670	1450
487	699	533	850	579	998	625	1165	671	1456
488	703	534	852	580	998	626	1170	672	1470
489	704	535	853	581	998	627	1175	673	1482
490	704	536	859	582	1006	628	1176	674	1490
491	722	537	860	583	1007	629	1177	675	1497
492	724	538	860	584	1007	630	1179	676	1513
493	727	539	862	585	1008	631	1183	677	1514
494	728	540	864	586	1011	632	1187	678	1555
495	731	541	865	587	1015	633	1198	679	1598
496	733	542	879	588	1018	634	1199	680	1613
497	738	543	882	589	1018	635	1212	681	1617
498	738	544	883	590	1026	636	1212	682	1638
499	745	545	886	591	1030	637	1218	683	1932
500	747	546	887	592	1030	638	1235	684	2128
501	747	547	888	593	1031	639	1242		
502	747	548	892	594	1042	640	1249		
503	757	549	893	595	1050	641	1275		
504	761	550	896	596	1056	642	1279		
505	761	551	896	597	1062	643	1282		
506	766	552	902	598	1062	644	1283		
507	770	553	912	599	1063	645	1285		

APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

Index	Residual Op Times	Index	Residual Op Times	Index	Residual Op Times
1	3	46	586	91	1120
2	5	47	592	92	1157
3	9	48	599	93	1176
4	14	49	599	94	1221
5	23	50	618	95	1247
6	25	51	618	96	1249
7	26	52	625	97	1251
8	30	53	630	98	1337
9	31	54	650	99	1389
10	49	55	658	100	1474
11	57	56	684	101	1503
12	89	57	692	102	1534
13	99	58	703	103	1585
14	106	59	723	104	1599
15	126	60	730	105	1740
16	156	61	741	106	2383
17	156	62	743		
18	161	63	748		
19	166	64	750		
20	174	65	764		
21	185	66	771		
22	205	67	778		
23	230	68	779		
24	270	69	814		
25	280	70	830		
26	323	71	849		
27	341	72	854		
28	352	73	874		
29	382	74	910		
30	382	75	931		
31	386	76	946		
32	391	77	971		
33	396	78	985		
34	434	79	987		
35	458	80	1017		
36	475	81	1022		
37	483	82	1039		
38	503	83	1051		
39	518	84	1067		
40	534	85	1069		
41	553	86	1070		
42	554	87	1070		
43	570	88	1072		
44	582	89	1105		
45	584	90	1112		

APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

A. CONTENTS OF APPENDIX C

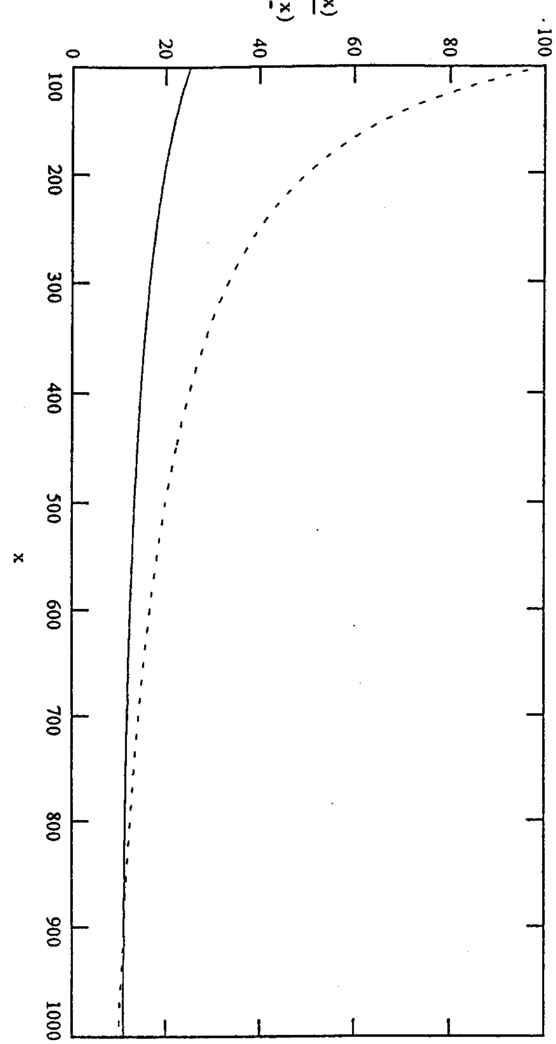
Appendix C contains 10 Mathcad graphical solution printouts showing the behavior of the two curves f(x) and g(x) from a macro-view for different combinations of input cost "u", cost ratio pairs, parameter values, and component HT. This appendix compliments the discussion in Chapter 4 about Mathcad graphical solution sensitivity and can be used as a tool to estimate the confidence limits of the solution for x.

APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 11000 \quad w := 20000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]}\,dt + \frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w\cdot\int_x^y \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

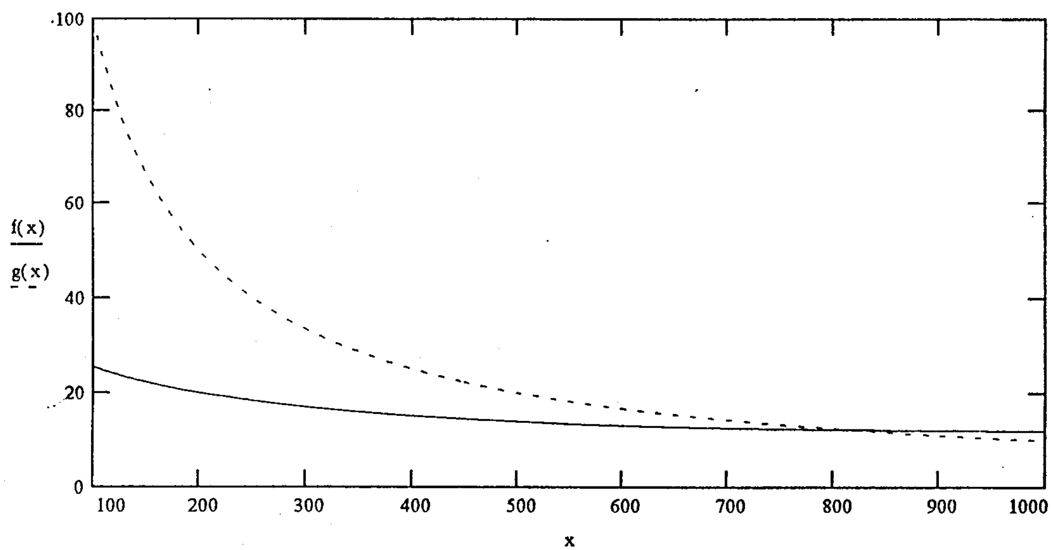


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 12000 \quad w := 20000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]}\,dt + \frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w\cdot\int_x^{y} \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

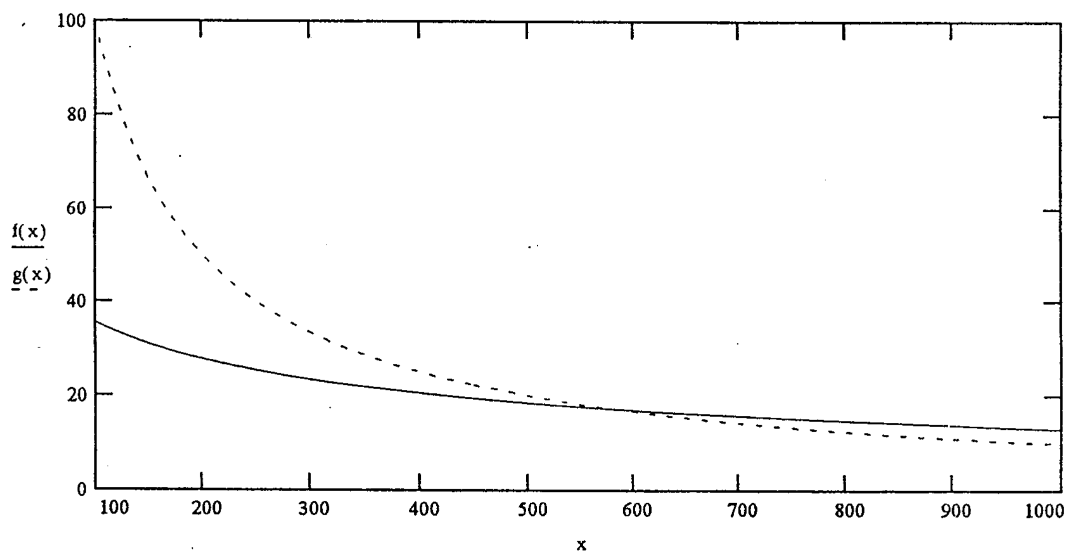


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 13000 \quad w := 30000 \qquad a := 2000 \quad c := 1.2 \quad b := 700 \quad d := 2.0 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d+\left(\frac{t+x}{a}\right)^c-\left(\frac{x}{a}\right)^c\right]}\,dt + \frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^d-\left(\frac{y}{a}\right)^c+\left(\frac{x}{a}\right)^c\right]} + w\cdot\int_x^{y} \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c-\left(\frac{x}{a}\right)^c+\left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

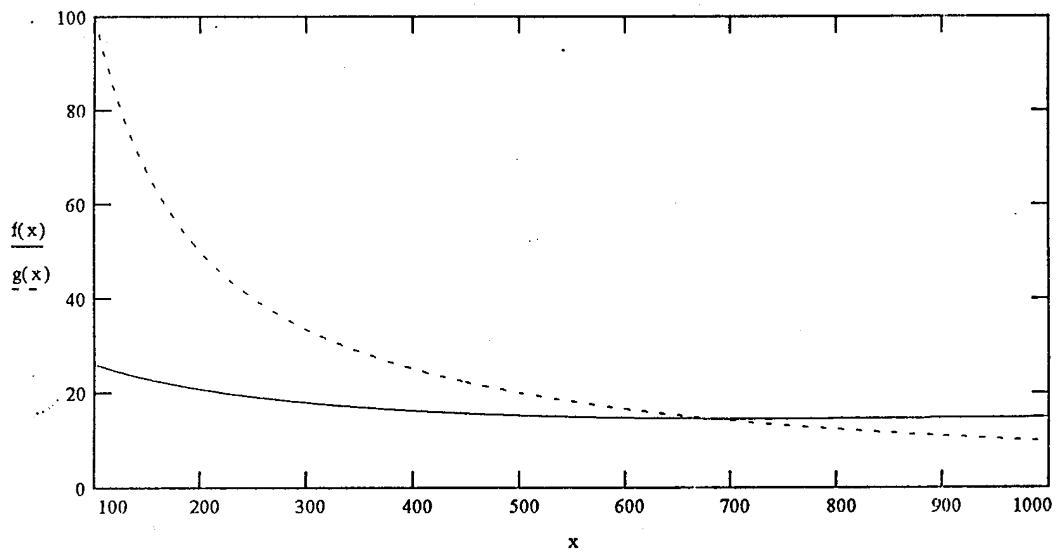


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 15000 \quad w := 20000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

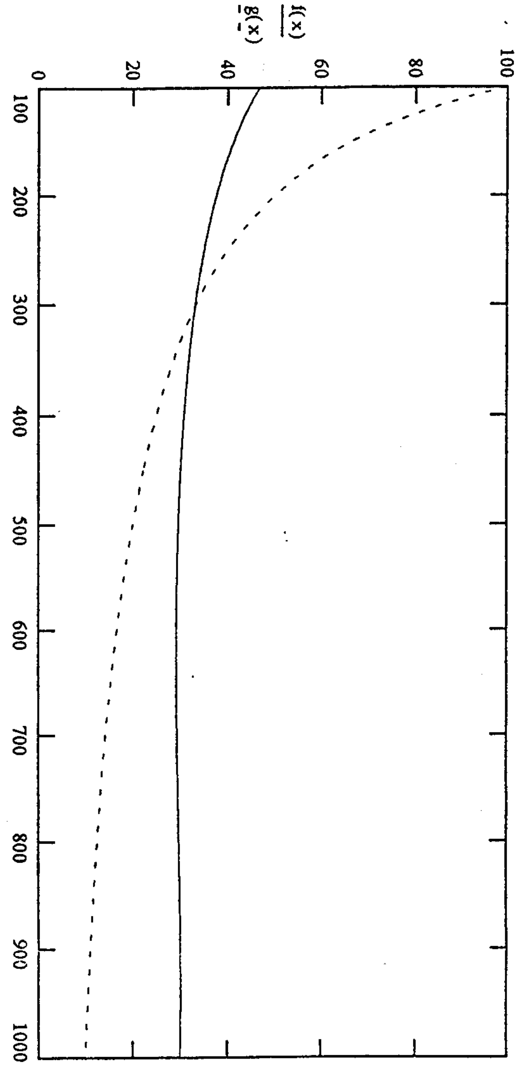


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 30000 \quad w := 80000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d+\left(\frac{t+x}{a}\right)^c-\left(\frac{x}{a}\right)^c\right]}\,dt+\frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^d-\left(\frac{y}{a}\right)^c+\left(\frac{x}{a}\right)^c\right]}+w\cdot\int_x^y \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c-\left(\frac{x}{a}\right)^c+\left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

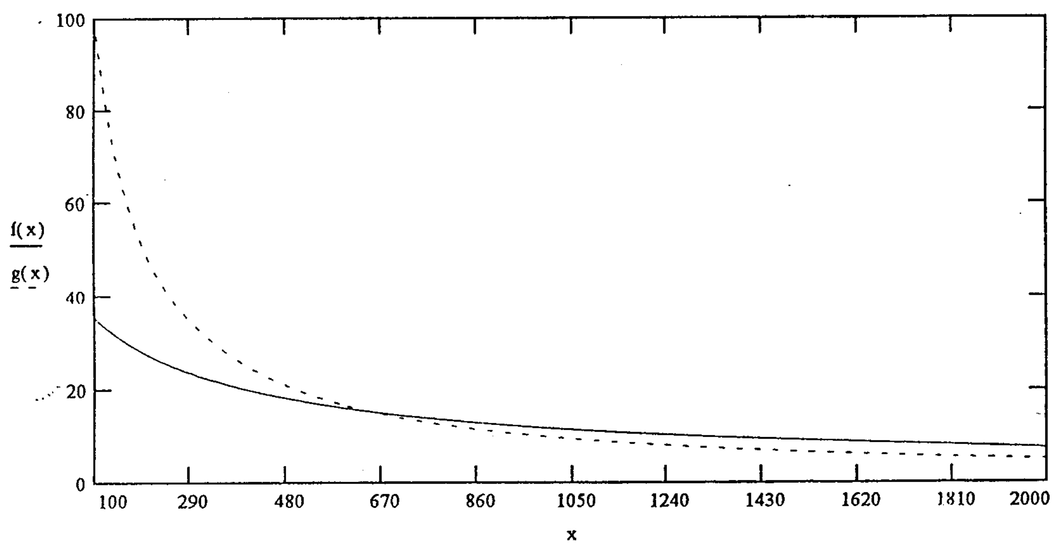


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 15000 \quad w := 30000 \qquad a := 2000 \quad c := 1.2 \qquad b := 1000 \quad d := 1.5 \qquad y := 2000 \qquad x := 100..2000$

$$f(x) := u\cdot\int_{0}^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^{d}\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^{d}+\left(\frac{t+x}{a}\right)^{c}-\left(\frac{x}{a}\right)^{c}\right]}\,dt+\frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^{d}-\left(\frac{y}{a}\right)^{c}+\left(\frac{x}{a}\right)^{c}\right]}+w\cdot\int_{x}^{y}\frac{1}{t}\cdot\left(\frac{1}{a}\right)^{c}\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^{c}-\left(\frac{x}{a}\right)^{c}+\left(\frac{t-x}{b}\right)^{d}\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

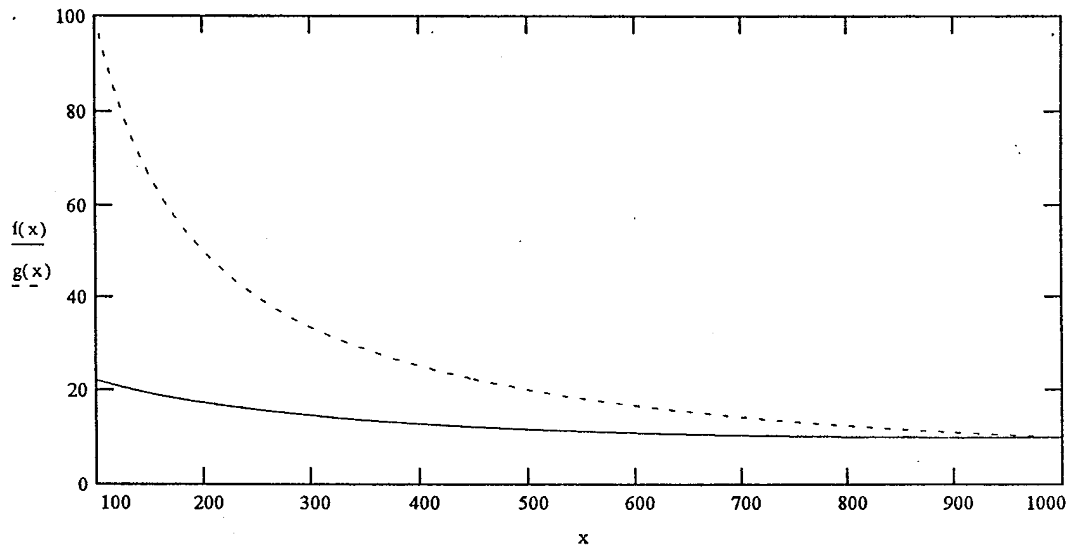


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 10000 \quad w := 10000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

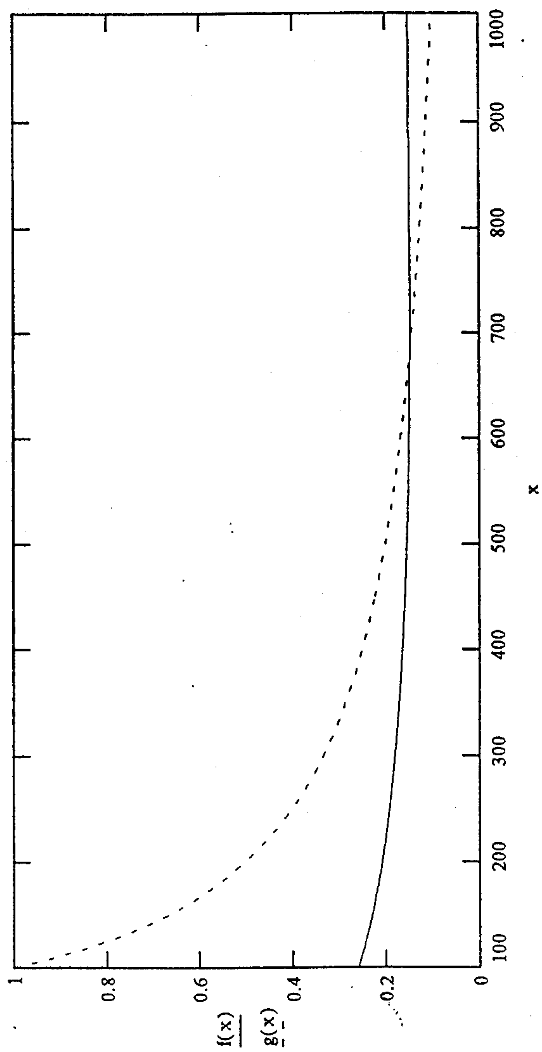


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 100 \quad v := 150 \quad w := 200 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]}\,dt + \frac{v}{y}\cdot e^{-\left[\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w\cdot\int_x^y \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$

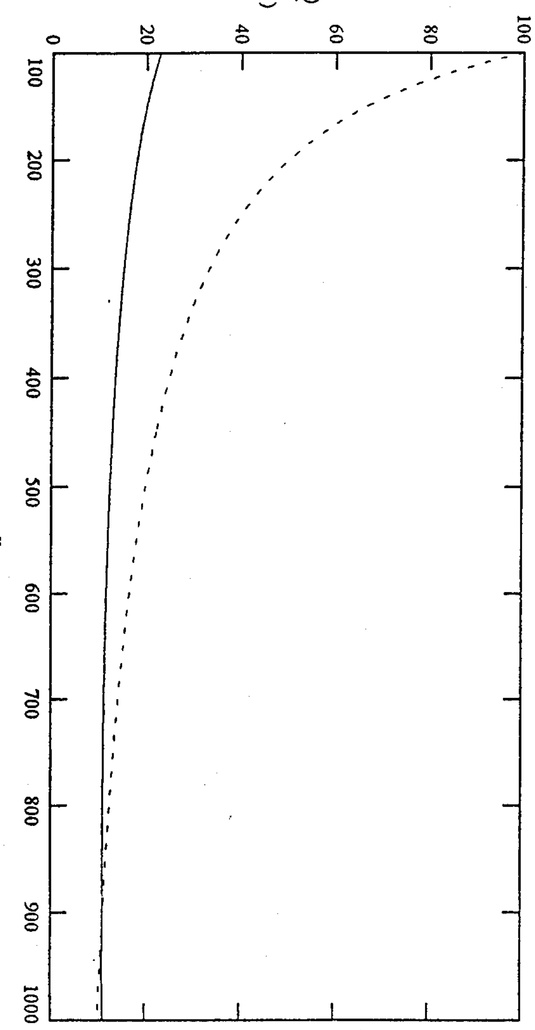


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 11000 \quad w := 12000 \qquad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

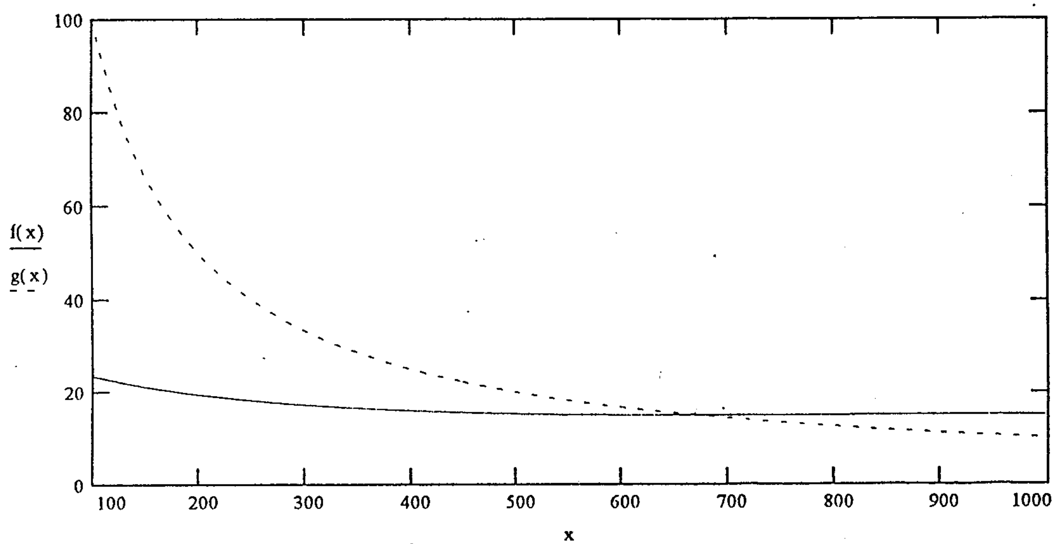


APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

u := 10000 v := 15000 w := 20000 a := 4000 c := 1.2 b := 700 d := 2.0 y := 1000 x := 100.. 1000

$$f(x) := u\cdot\int_0^{y-x} \frac{1}{t+x}\cdot\left(\frac{1}{b}\right)^d\cdot d\cdot t^{d-1}\cdot e^{-\left[\left(\frac{t}{b}\right)^d+\left(\frac{t+x}{a}\right)^c-\left(\frac{x}{a}\right)^c\right]}\,dt + \frac{v}{y}\cdot e^{\left[-\left(\frac{y-x}{b}\right)^d-\left(\frac{y}{a}\right)^c+\left(\frac{x}{a}\right)^c\right]} + w\cdot\int_x^y \frac{1}{t}\cdot\left(\frac{1}{a}\right)^c\cdot c\cdot t^{c-1}\cdot e^{-\left[\left(\frac{t}{a}\right)^c-\left(\frac{x}{a}\right)^c+\left(\frac{t-x}{b}\right)^d\right]}\,dt$$

$$g(x) := \frac{u}{x}$$



APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

A. CONTENTS OF APPENDIX D

Appendix D is a tabulation of solutions for optimal NBT "x" for 26 different combinations of cost ratio pairs, engine/component Weibull parameters, and component HT. Each box is a separate combination, and each parameter and HT combination was inputted for the same range of cost ratios as shown in the matrix on the right of each box. The input values for the Weibull parameter and component HT are shown in bold.

For example, the first scenario on page 88 shows bolded values of 2000, 1.0, 500, 1.2, and 1000 for θ component, β component, θ engine, β engine and component HT, respectively. The corresponding solution for "x" for these input values, from the optimizing equation for NBT in Mathcad, are tabulated to the right for each cost ratio pair. For a cost ratio pair (Ci/Cn, Cf/Cn) = (1.1, 1.2) the solution for "x" is 910. This means that for a component with a HT of 1000 and the given combination of parameters the accumulated number of operating hours when the component should be inspected when the engine has failed is 910 hours. Inspecting the component on a failed engine any time before this is not cost effective. For a cost ratio pair of (1.5, 2) the solution for "x" is 670, and so on.

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	910	895	865	720	260	168
	1.5		710	670	560	250	165
	2				484	240	160
	3					226	155
	6						145

Parameter	Parameter Values		
θ Component (a)	2000	**4000**	6000
β Component (c)	1.0	**1.2**	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	912	908	897	870	675	500
	1.5		720	705	670	535	435
	2				567	464	390
	3					390	340
	6						265

Parameter	Parameter Values		
θ Component (a)	2000	4000	**6000**
β Component (c)	1.0	1.2	**1.5**
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	915	912	908	900	863	825
	1.5		728	720	710	663	630
	2				598	563	535
	3					461	441
	6						525

Parameter	Parameter Values		
θ Component (a)	2000	**4000**	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	912	907	895	863	600	405
	1.5		720	703	660	485	365
	2				560	425	335
	3					360	297
	6						236

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values		
θ Component (a)	2000	4000	**6000**
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	915	910	930	885	780	640
	1.5		725	715	685	588	505
	2				580	500	436
	3					413	368
	6						277

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	1.0	**1.2**	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	910	893	860	720	300	205
	1.5		710	670	565	285	200
	2				492	273	196
	3					254	187
	6						170

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	1.0	1.2	**1.5**
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	910	895	863	735	358	260
	1.5		710	673	580	340	255
	2				507	320	245
	3					294	234
	6						205

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	**700**	1000
β Engine (d)	1.2	**1.5**	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	910	890	855	700	240	155
	1.5		685	640	525	230	150
	2				445	218	145
	3					200	140
	6						125

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	700	**1000**
β Engine (d)	1.2	1.5	**2.0**
Component HT (y)	**1000**		2000

Solution Values for "x"

Ci/Cn \ Cf/Cn	1.2	1.5	2	3	6	8
1.1	904	888	850	685	225	140
1.5		660	610	490	210	135
2				402	195	130
3					175	122
6						105

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	**700**	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"

Ci/Cn \ Cf/Cn	1.2	1.5	2	3	6	8
1.1	908	895	860	710	245	155
1.5		690	645	530	235	153
2				448	220	147
3					200	140
6						124

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	700	**1000**
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"

Ci/Cn \ Cf/Cn	1.2	1.5	2	3	6	8
1.1	907	893	855	695	240	145
1.5		675	627	510	220	140
2				420	202	135
3					182	128
6						110

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	1.2	**1.5**	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"

Ci/Cn \ Cf/Cn	1.2	1.5	2	3	6	8
1.1	910	895	860	715	260	165
1.5		703	665	560	250	163
2				487	243	160
3					230	158
6						147

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	**2000**	4000	6000			1.2	1.5	2	3	6	8
β Component (c)	**1.0**	1.2	1.5		1.1	905	890	860	710	260	165
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		695	660	560	250	163
β Engine (d)	1.2	1.5	**2.0**		2				492	245	160
					3					237	154
Component HT (y)	**1000**		2000		6						

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	**2000**	4000	6000			1.2	1.5	2	3	6	8
β Component (c)	**1.0**	1.2	1.5		1.1	1820	1765	1545	820	258	165
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		1498	1305	795	258	165
β Engine (d)	**1.2**	1.5	2.0		2				775	258	165
					3					258	165
Component HT (y)	1000		**2000**		6						165

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	2000	**4000**	6000			1.2	1.5	2	3	6	8
β Component (c)	1.0	**1.2**	1.5		1.1	1835	1815	1760	1520	700	488
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		1520	1460	1288	685	485
β Engine (d)	**1.2**	1.5	2.0		2				1175	675	482
					3					657	477
Component HT (y)	1000		**2000**		6						466

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	2000	4000	**6000**			1.2	1.5	2	3	6	8
β Component (c)	1.0	1.2	**1.5**		1.1	1840	1830	1805	1740	1300	1010
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		1540	1510	1450	1170	965
β Engine (d)	**1.2**	1.5	2.0		2				1300	1085	925
					3					990	870
Component HT (y)	1000		**2000**		6						780

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values		
θ Component (a)	2000	**4000**	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	1830	1810	1760	1530	610	400
	1.5		1520	1460	1280	600	400
	2				1165	596	398
	3					583	395
	6						386

Parameter	Parameter Values		
θ Component (a)	2000	4000	**6000**
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	1835	1825	1795	1700	985	660
	1.5		1533	1500	1400	930	645
	2				1262	885	640
	3					830	616
	6						585

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	1.0	**1.2**	1.5
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	1820	1740	1425	775	292	201
	1.5		1460	1250	760	292	201
	2				750	292	201
	3					292	201
	6						201

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	1.0	1.2	**1.5**
θ Engine (b)	**500**	700	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	**1000**		2000

Solution Values for "x"		Cf/Cn 1.2	1.5	2	3	6	8
Ci/Cn	1.1	1810	1700	1300	758	345	255
	1.5		1440	1195	750	345	255
	2				740	345	255
	3					345	255
	6						255

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	**700**	1000
β Engine (d)	1.2	**1.5**	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"	Cf/Cn	1.2	1.5	2	3	6	8
Ci/Cn	1.1	1810	1740	1485	750	230	148
	1.5		1415	1230	750	230	148
	2				750	230	148
	3					230	148
	6						148

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	700	**1000**
β Engine (d)	1.2	1.5	**2.0**
Component HT (y)	1000		**2000**

Solution Values for "x"	Cf/Cn	1.2	1.5	2	3	6	8
Ci/Cn	1.1	1800	1720	1435	705	210	132
	1.5		1343	1150	675	210	132
	2				655	210	132
	3					210	132
	6						132

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	**700**	1000
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"	Cf/Cn	1.2	1.5	2	3	6	8
Ci/Cn	1.1	1815	1750	1500	758	235	150
	1.5		1415	1225	730	235	150
	2				705	235	150
	3					235	150
	6						150

Parameter	Parameter Values		
θ Component (a)	**2000**	4000	6000
β Component (c)	**1.0**	1.2	1.5
θ Engine (b)	500	700	**1000**
β Engine (d)	**1.2**	1.5	2.0
Component HT (y)	1000		**2000**

Solution Values for "x"	Cf/Cn	1.2	1.5	2	3	6	8
Ci/Cn	1.1	1810	1735	1460	715	215	137
	1.5		1365	1160	675	214	137
	2				640	213	137
	3					210	137
	6						137

APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	**2000**	4000	6000			1.2	1.5	2	3	6	8
β Component (c)	**1.0**	1.2	1.5		1.1	1805	1755	1530	795	255	163
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		1480	1320	790	255	163
β Engine (d)	1.2	**1.5**	2.0		2				785	255	163
					3					255	163
Component HT (y)	1000		**2000**		6						163

Parameter	Parameter Values					Solution Values for "x"					
						Cf/Cn					
θ Component (a)	**2000**	4000	6000			1.2	1.5	2	3	6	8
β Component (c)	**1.0**	1.2	1.5		1.1	1810	1750	1530	800	255	165
θ Engine (b)	**500**	700	1000	Ci/Cn	1.5		1495	1355	800	255	165
β Engine (d)	1.2	1.5	**2.0**		2				800	255	165
					3					255	165
Component HT (y)	1000		**2000**		6						165

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